National Oceanic and Atmospheric Administration (NOAA)
Atlantic Oceanographic and Meteorological Laboratory (AOML)

Physical Oceanography Division (PhOD)

February 16, 2010

Physical Oceanography Division

The Physical Oceanography Division (PhOD) is a part of the Atlantic Oceanographic and Meteorological Laboratory (AOML) together with the Ocean Chemistry and Hurricane Research Divisions. The Physical Oceanography Division carries out interdisciplinary scientific investigations of the physics of ocean currents and water properties, and on the role of the ocean in climate, weather, and ecosystems. The tools used range from sensors on deep ocean moorings to satellite-based instruments to measurements made on research and commercial shipping vessels and autonomous vehicles and include data analyses and numerical model as well at theoretical approaches.

Some major areas of research are:

* The dynamics and variability of ocean currents;
* The redistribution of heat, salt and momentum through the oceans;
* The interactions between oceans, climate, and coastal environments.
* The influence of climate changes and of the ocean on extreme weather events.

These studies have important applications to ecosystems, hurricanes and global climate. To learn more about the work we do please see the PhOD web site:

http://www.aoml.noaa.gov/phod/index.php

The following pages provide highlights of PhOD ongoing research projects that are either led by or involve PhOD investigators together with essential science support personnel from NOAA and from University of Miami/Cooperative Institute for Marine and Atmospheric Studies (CIMAS). Many of these projects are also led by or involve investigators from other AOML Divisions and national and international institutions. For additional details about these projects, please contact the AOML investigators working in the projects, the PhOD website, or the list of publications at the end of this report.

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CIMAS/UM - *The Cooperative Institute for Marine and Atmospheric Studies (*CIMAS*) is a research institute of the* University of Miami

The Ship of Opportunity Program

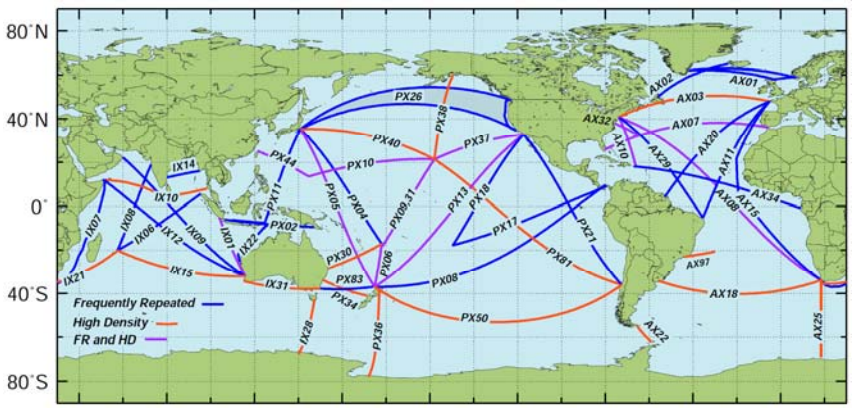
Gustavo Goni, Molly Baringer, and Silvia Garzoli

The Ship of Opportunity Program (SOOP) addresses both scientific and operational goals for building a sustained ocean observing system. There are currently about 400 ships aiding NOAA in the collection of meteorological observation and more than 50 ships dedicated to collecting oceanographic data. NOAA's efforts are a key component of the global SOOP administered by the United Nation's World Meteorological Organization (WMO) and the International Oceanographic Commission (IOC) to collect marine observations. NOAA's Atlantic Oceanographic Meteorological Laboratory (AOML) manages this program. AOML continuously recruits ships to assist scientists in collecting oceanographic data from all world oceans. Once a vessel has been recruited it is equipped with the instrumentation required for each cruise.

AOML operates a global Expendable Bathythermograph (XBT) program that utilizes approximately 50 ships of the SOOP to monitor the upper ocean thermal structure along 18 transects in all ocean basins. An XBT is a temperature probe that is launched from the bridge wing of a ship or the stern by ship personnel 4 to 6 times per day. The data are logged to a computer provided by AOML, where it is processed and formatted for satellite transmission in real-time through the Global Telecommunications System (GTS). The data are then used by national and international organizations, universities and government laboratories for weather and climate forecasting and for climate research.

AOML currently operates ThermoSalinoGraphs (TSG) installed in four Ships of Opportunity in the Pacific and Atlantic, including Royal Caribbean Cruise Line's Explorer of the Seas and the *M/V* Explorer of the Semester At Sea Program of the University of Virginia. TSG measure salinity and sea surface temperature every 10 seconds, or approximately 100 m along the ship track and are critical to validate weather and climate model results and satellite observations.

The SOOP also contributes to the deployment of a worldwide array of satellite-tracked drifting buoys (drifters) measuring sea surface temperature and near surface currents, deployment of Argo profiling floats, and installation of thermosalinographs.



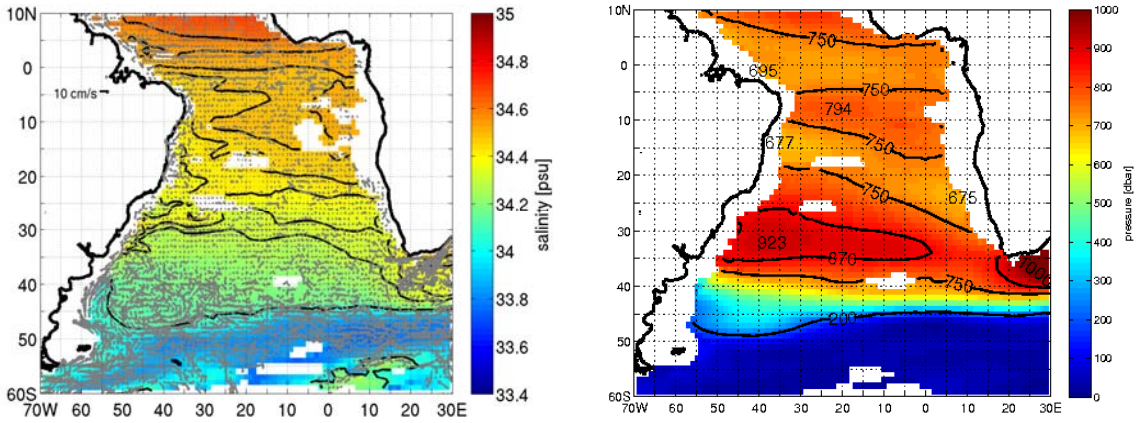
TSG observations obtained from ships of the SOOP since 2001 and distributed through the Global Telecommunication System (GTS). XBT network containing OceanObs99 recommendations and current proposed transects. XBT observations transmitted in (red) real- and (blue) delayed-time in 2008. The real-time data were obtained from the GTS and the Coriolis data center. The delayed-time data were obtained from the Global Temperature and Salinity Profile Programme managed by NOAA/NODC.

Argo Profiling Floats

Silvia Garzoli and Claudia Schmid

Argo is an international program designed to deploy and maintain an array of 3,000 profiling floats to monitor the upper 2km of the global ocean. The role of AOML in Argo is twofold: a) AOML is the US Argo Data Assembly Center (DAC) and as such, collects all the US Argo data and makes them available to the operational centers and scientists in real time through Global telecommunication System (GTS) and the Argo Global (DAC). To achieve this US DAC has developed and maintained an automatic system for decoding, quality control, and distribution of data obtained from the US Argo floats. The system runs in a 24/7 mode. b) AOML is also responsible for deploying all the US Atlantic Ocean floats. New original and resourceful initiatives were taken to deploy floats in areas not transited by volunteer ships ships. AOML was also successful in forming agreements with South American and South African countries to jointly use their ships for float deployments in undersampled areas. As part of the South Atlantic Argo Regional center, PhOD conducted a training program in conjunction with the US Navy, in Lagos, Nigeria in March 2009.

AOML scientists use Argo data among others, to analyze water properties and circulation in various regions of the world ocean. The figures show results of an analysis of the water properties of the Antarctic Intermediate Water (AAIW) and its distribution in the South Atlantic. This study is relevant to better understand the pathways of the Atlantic Meridional Overturning Circulation. The AAIW water mass is characterized by a minimum of the salinity (Fig. 1, left) at intermediate depth (Fig. 1, right). The mean velocity field at intermediate depth derived from float trajectories is shown in Fig. 1 (left). The analysis supports earlier conclusions that the intermediate depth flow largely follows an anticyclonic pathway under the subtropical gyre. However, interesting new features in the pathways are found, for example: (1) the existence of three branches of westward to northwestward flow that are fed by the Benguela Current (only two have been described before); (2) two pathways through which the water from the Benguela Current Extension feeds into the Intermediate Western Boundary Current, one turns north at the western boundary, while the other one turns north about 10^{o} farther offshore.



The water mass properties of the Antarctic Intermediate Water and circulation at 800 to 1100 dbar. Left: salinity at the salinity minimum and velocity vectors. Right: pressure at the depth of the salinity minimum.

The Global Drifter Program
Satellite-tracked Surface Drifting Buoys

Rick Lumpkin and Silvia Garzoli

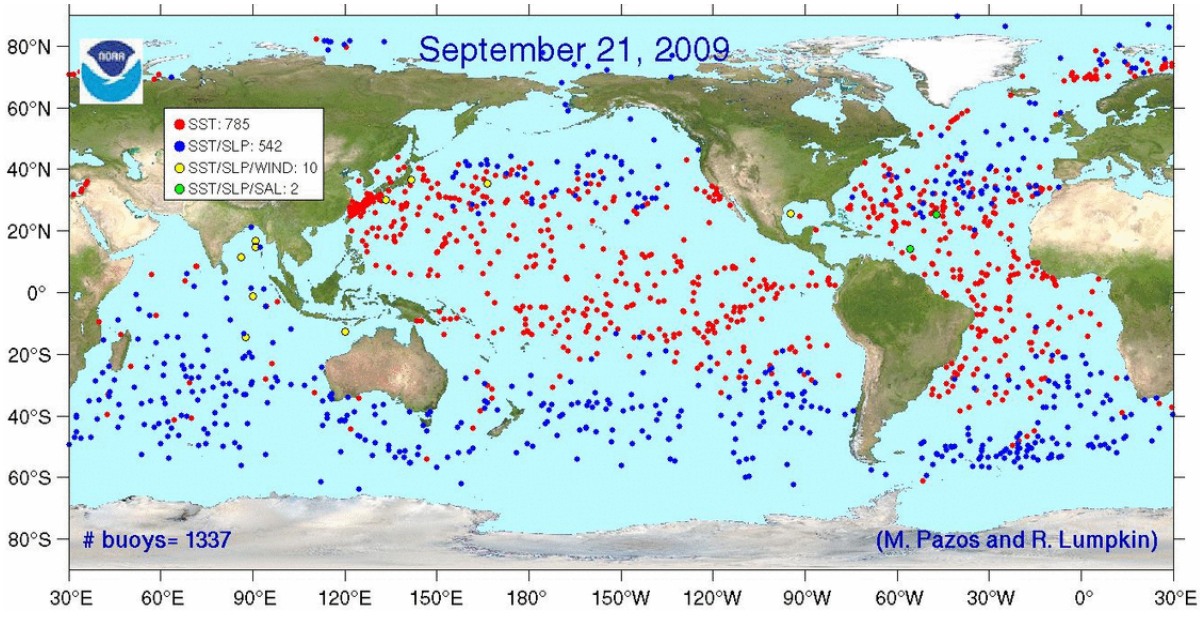
NOAA's Global Drifter Program (GDP) is the principal component of the Global Surface Drifting Buoy Array, a branch of NOAA's Global Ocean Observing System and a scientific project of the Data Buoy Cooperation Panel. Its objectives are to:

1. Maintain a global 5°x5° array of 1250 satellite-tracked surface drifting buoys to meet the need for an accurate and globally dense set of in-situ observations of mixed layer currents, sea surface temperature, atmospheric pressure, winds and salinity, and

2. Provide a data processing system for scientific use of these data.

These data support short-term (seasonal to interannual) climate predictions as well as climate research and monitoring. The drifters are also used to collect meteorological observations for improved weather forecasting.

NOAA's Atlantic Oceanographic and Meteorological Laboratory houses two vital components of the Global Drifter Program: the drifter Data Assembly Center and the Drifter Operations Center**.** These components of the GDP coordinate deployments, process the drifter data, archive the data, maintain metadata files describing each drifter deployed develop and distribute data-based products, and maintain at the GDP website:
(http://www.aoml.noaa.gov/phod/dac/gdp.html).

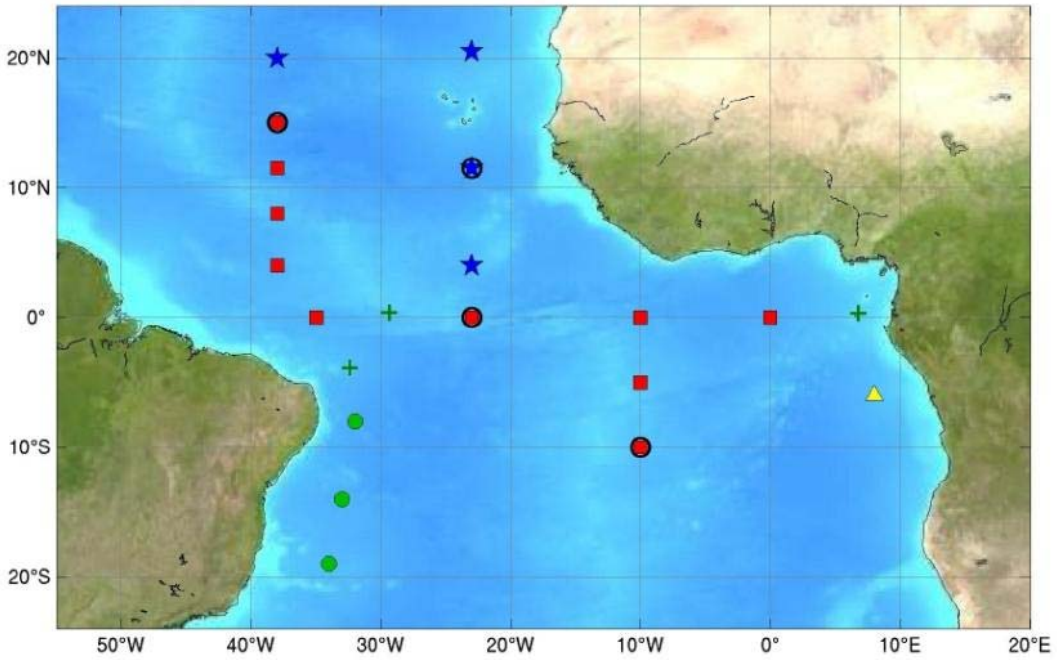


Status of the global array on 21 September 2009. A large number of deployments in the Kuroshio region has temporarily increased the size of the array to 1337 drifters, while the annually-averaged size is close to 1250 drifters.

The PIRATA Northeast Extension: Observing Tropical Atlantic Climate Variability

Rick Lumpkin, Claudia Schmid, and Christopher Meinen

The Prediction and Research Moored Array in the Tropical Atlantic (PIRATA) is a joint project of Brazil, France and the United States of America. PIRATA aims to improve our knowledge and understanding of ocean-atmosphere variability in the tropical Atlantic. Implementation of PIRATA started in 1997 with an array of backbone moored ATLAS buoys, similar to the Tropical Atmosphere-Ocean (TAO) array of the equatorial Pacific. Starting in late 2005, extensions were added to the backbone array in key regions, including the US-led PIRATA Northeast Extension (PNE).



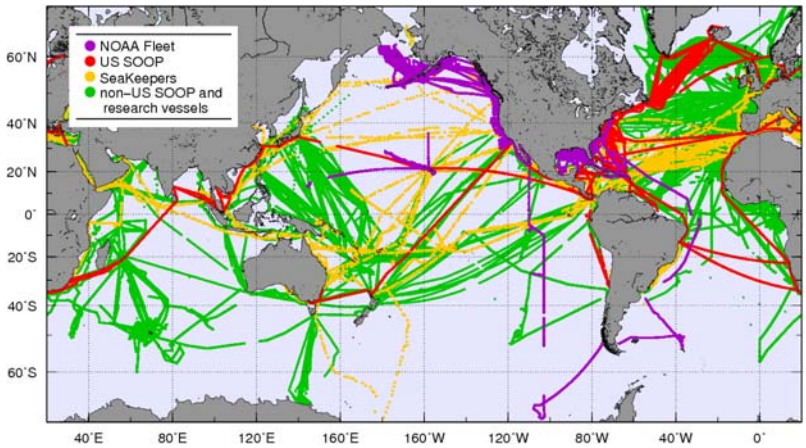
The PIRATA backbone of buoys (red squares), the Northeast Extension (blue stars) led by the United States, the Southwest Extension (green circles) led by Brazil, the Southeast Extension pilot site (yellow triangle), and island-based observation sites (green crosses). Buoys with barometers and longwave radiometers, capable of estimating net ocean/atmosphere heat fluxes, are indicated with black circles.

PNE is a joint AOML and PMEL effort to extend and maintain the array into the tropical north Atlantic, a region of strong climate variations with impacts upon rainfall rates and storm strikes for the surrounding regions of Africa and the Americas. Important processes in this region include the formation of Cape-Verde type hurricanes, seasonal migration of the Intertropical Convergence Zone (ITCZ) and the Guinea Dome, interannual to decadal variations of the ITCZ migration associated with rainfall anomalies in Africa and the Americas, off-equatorial heat advection by Tropical Instability Waves, and overturning-related ventilation of the oxygen minimum zone. AOML organizes and leads the annual cruises to visit the buoy sites and collect a suite of meteorological and oceanographic observations in the region, while PMEL provides the equipment and technicians for the mooring operations.

Thermosalinograph Operations

Gustavo Goni and Francis Bringas

The Thermosalinograph (TSG) operation is one of the components of the Ship Of Opportunity Program (SOOP) at AOML, and has been producing oceanographic observations since 1991. TSGs are instruments that continuously measure the sea surface temperature and sea surface salinity along a ship's track. Research vessels gather TSG observations from various regions of the global ocean, while ships of opportunity – cruise and cargo vessels – obtain long time series of temperature and salinity data for frequently-repeated transects. AOML's TSG operations are based on obtaining data from NOAA's fleet of research vessels, as well as from ships of opportunity. Data are received in real-time mode, typically one file per day containing 24 hours of data, and are subjected to quality-control procedures. Quality-control approved TSG records are distributed on the Global Telecommunication System (GTS) in real-time. The data are archived at the National Oceanographic Data Center (NODC) in Silver Spring, Maryland and the French Research Institute for Exploration of the Sea (IFREMER) in Brest, France. AOML is currently extending its quality-control procedures to develop a mechanism for automatically detecting equipment malfunctions and the need for instrument calibration.



The figure (shows) the location of TSG observations produced by AOML and other institutions since 2001. TSG observations obtained from the NOAA fleet are predominantly gathered off U.S. coastal regions and represent more than 5.5 million records, of which more than 35% are located at latitudes above 45°. TSG observations obtained from ships of opportunity comprise more than 4.6 millions records in the Atlantic Ocean, with almost 1 million records obtained at high latitudes. The TSG data set, particularly high latitude observations, will soon be of great importance for two upcoming satellite missions. Salinity data at high latitudes will be crucial for validating and calibrating sea surface salinity fields obtained from the European Space Agency's SMOS (Soil Moisture and Ocean Salinity) mission, scheduled for in November 2009, and NASA's Aquarius mission, scheduled for launch in 2010. SOOP's TSG observations have many applications, including their use in climate and ocean dynamics research, determination of boundary regions in ocean currents, and as input for climate and weather forecast models. A large portion of the TSG operation also supports efforts of the global inventory of carbon dioxide in the oceans, a project led at AOML by Dr. Rik Wanninkhof. TSG data have enhanced global data collection efforts for close to 20 years and have been critical to understanding long-term changes in the marine environment.

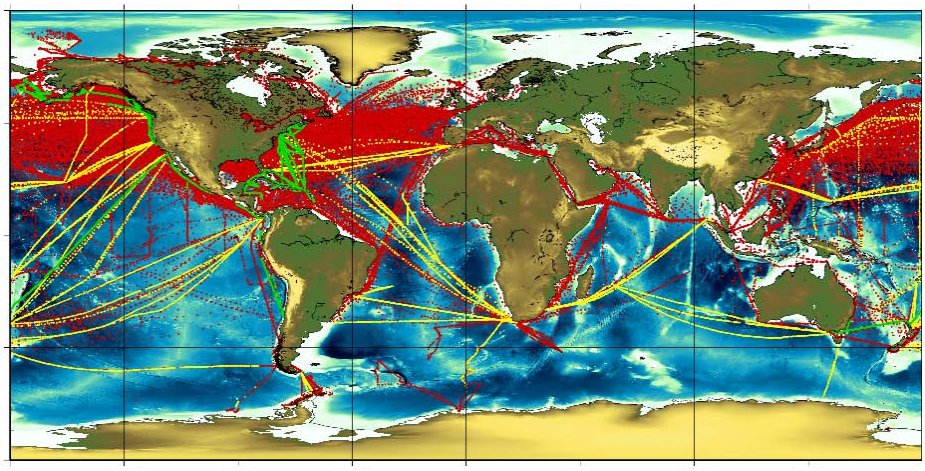
Amver SEAS Program

Gustavo Goni, Molly Baringer and Silvia Garzoli

Shipboard Environmental (data) Acquisition System (SEAS) is a Windows-based, real-time Shipboard Environmental data Acquisition and transmission System developed at AOML in 2001 with the assistance of the NOAA's Office of Marine and Aviation Operations. This software enables various types of atmospheric and oceanographic data to be obtained from ships and transmitted in real- time to AOML for quality control. The data are subsequently transmitted to the Global Telecommunication System and several operational databases for use by scientists as input to weather and climate forecast models. A major component of SEAS 2K is the acquisition of ocean data using expendable bathythermographs (XBTs). AOML and the Scripps Institution of Oceanography are the principal users of the SEAS software, with AOML being responsible for close to 90% of all 25,000 XBTs deployed annually. In collaboration with the NOAA's National Marine Fisheries Service the software is also used to investigate the frontal variability of the Gulf Stream using XBTs and thermosalinograph observations from the M/V *Oleander*.

The National Weather Service uses SEAS 2K software to generate and transmit marine meteorological (MET) observations. Over 400 vessels operated by NOAA, the University-National Oceanographic Laboratory System (UNOLS), and the Coast Guard, as well vessels participating in NOAA's Volunteer Observing Ship Program, participate in reporting MET observations, which contain atmospheric, oceanographic, and position data acquired both manually and automatically by shipboard sensors. More than 200,000 SEAS 2K MET observation bulletins are transmitted annually.

Additionally, the Coast Guard uses AMVER reports, along with SEAS 2K MET observations, to support their AMVER vessel search and rescue program. The SEAS 2K software creates a series of reports that include a ship's medical personnel, point of departure, route, positions underway, and arrival to help locate able vessels near vessels in distress. Over 14,000 AMVER reports are transmitted annually to the Coast Guard. These reports have helped rescue more than 2,100 lives during the last seven years; SEAS 2K accounts for nearly 20% of the Coast Guard's AMVER reports. SEAS 2K is used for data transmissions by different NOAA line offices with applications to physical, biological, and meteorological marine studies.



Location of oceanographic (yellow=XBTs, green=TSGs) and meteorological (red) observations transmitted with SEAS 2K during 2007.

Deep Ocean Data Retrieval System

Ulises Rivero, Silvia Garzoli, and Christopher Meinen

On September 8, 2009, AOML completed a successful proof-of-concept field-test of a new deep ocean data retrieval system. The purpose of the cruise was to complete the first open ocean tests of the new deep ocean data retrieval system, which has now been named the "Adaptable Bottom Instrument Information Shuttle System (ABIISS)", a technology developed by AOML engineers. This system, once fully operational, will allow scientific instruments anchored on the ocean bottom to send their data back via expendable data pods that will release from the ocean floor on a programmable schedule. These data pods will float up to the sea surface and transmit their data back to land via satellite. The system has the potential to save significant amounts of financial and personnel resources by reducing the amount of ship time needed to support and maintain ocean time series measurement sites. Principle funding for this development project was provided by the OAR Assistant Administrators Discretionary Fund program for fiscal year 2008. Additional funding to support the one-day cruise in the Straits of Florida aboard the R/V F. G. Walton Smith was provided by the OAR Office of Climate Observations.

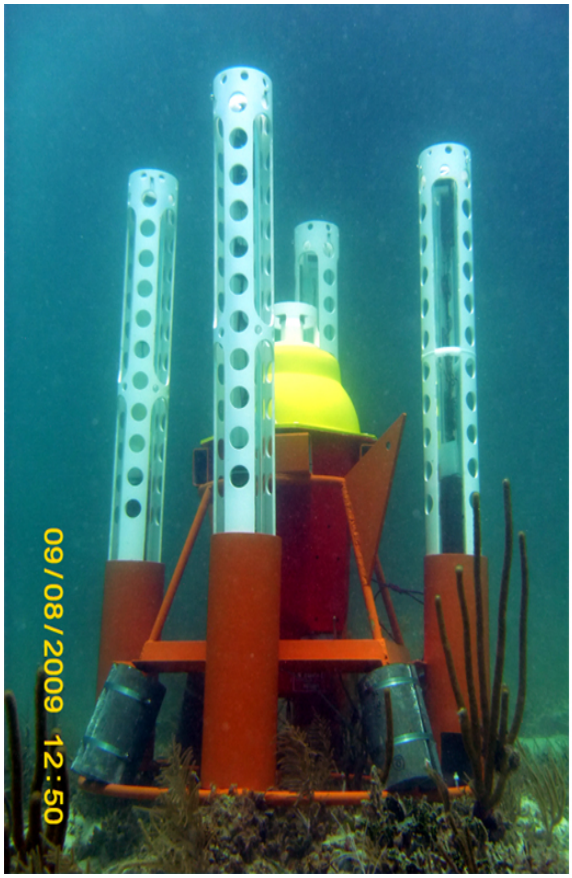


Photo of prototype ABIISS system with PIES in the Straits of Florida.

Data pod transmitting data via satellite after release.

NOAA/AOML Satellite Ocean Monitoring

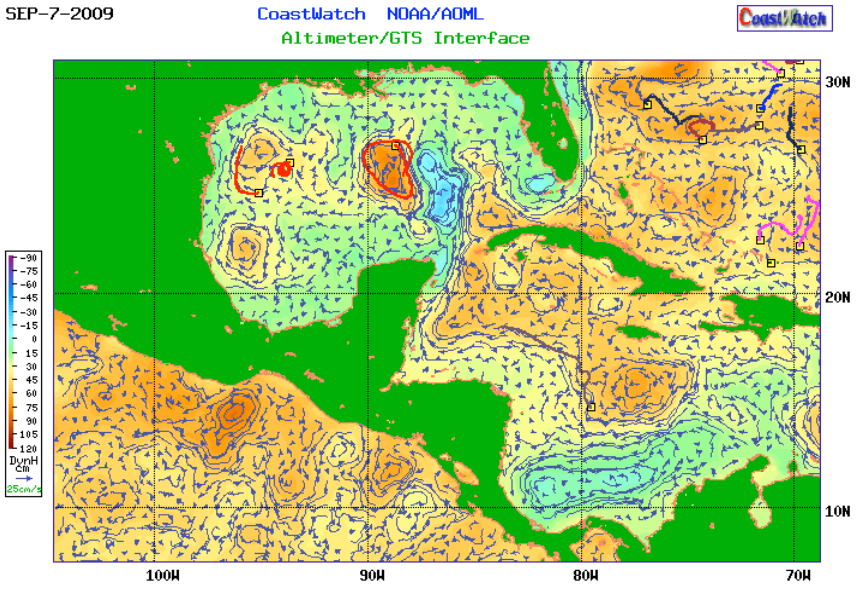
Gustavo Goni and Joaquin Trinanes

PhOD distributes on its web server (www.aoml.noaa.gov/phod/satprod) several products for climate and weather studies. The data used to derive these products come from a wide array of observing platforms such as satellite-derived sea height anomaly (SHA) and sea surface temperature (SST), temperature profiles from profiling floats and expendable bathythermographs (XBTs), and surface currents from drifters. Real-time global geostrophic surface currents, tropical cyclone heat potential, and long term time series of important oceanographic variables are available through the PhOD website.

CoastWatch

CoastWatch is a National Oceanic and Atmospheric Administration program that provides remotely sensed satellite and other environmental data to government decision makers and academic researchers. In a collaboration effort with NOAA/NESDIS, the Caribbean/Gulf of Mexico Regional Node is hosted at NOAA/AOML. This node is one of several sites throughout the United States set up for the processing and distribution of information in near real-time. The primary data source for CoastWatch data is the Advanced Very High Resolution Radiometer (AVHRR) on the NOAA series polar orbiting weather satellites.

Altimeter-derived geostrophic currents posted in real-time with surface drifter trajectories superimposed. These fields can be obtained from:
http://www.aoml.noaa.gov/phod/dataphod/work/trinanes/INTERFACE/index.html



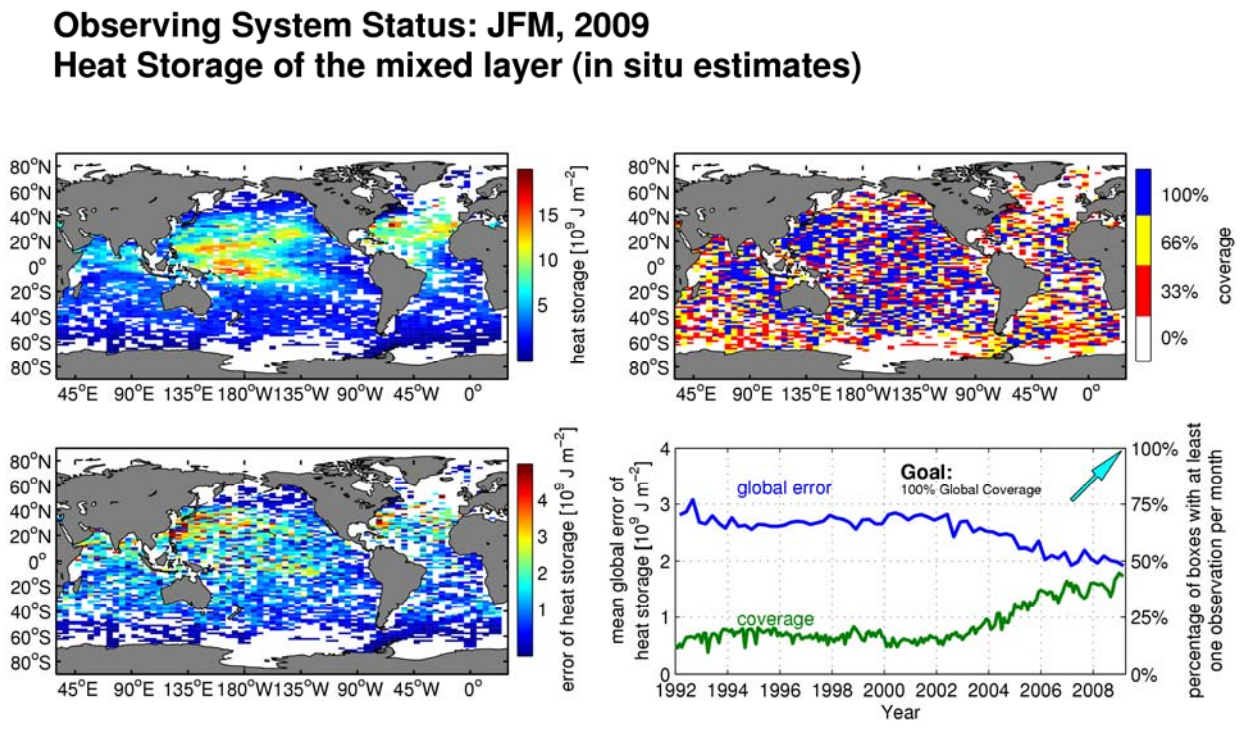
Altimeter-derived geostrophic currents overlaid over the dynamic height field for September 7, 2009. Drifter trajectories for the period UGUST 25 – September 7, 2009, are superimposed.

Evaluating the Ocean Observing System: Monitoring the Global Ocean Heat Storage

Claudia Schmid and Gustavo Goni

The PhOD creates reports that provide information needed to evaluate the accuracy of estimates of the global upper ocean heat storage and its time derivative. These reports include (a) locations where upper ocean temperatures were collected in each quarter, (b) how well the observations satisfy the Global Climate Observing System / Global Ocean Observing System (GOOS/GCOS) temperature requirements, (c) the areas where future observations are needed in order to improve the observing system, and (d) how successfully the system reduces the potential of a bias error. The analysis is based on profiles of temperature and salinity from various platforms (XBT, CTD, profiling floats) and starts in January 1992. Correlations between the in-situ estimates of the heat storage and sea height anomalies from altimetry are also used to extend the heat storage fields into regions where the coverage with in-situ data is poor.

AOML scientists use the estimates of the heat storage to work on various topics: (a) the issue of time-dependent biases between XBT profiles and other profiles due to the uncertainties of the fall rate of XBTs, (b) the variability of the heat storage and (c) the heat balance.

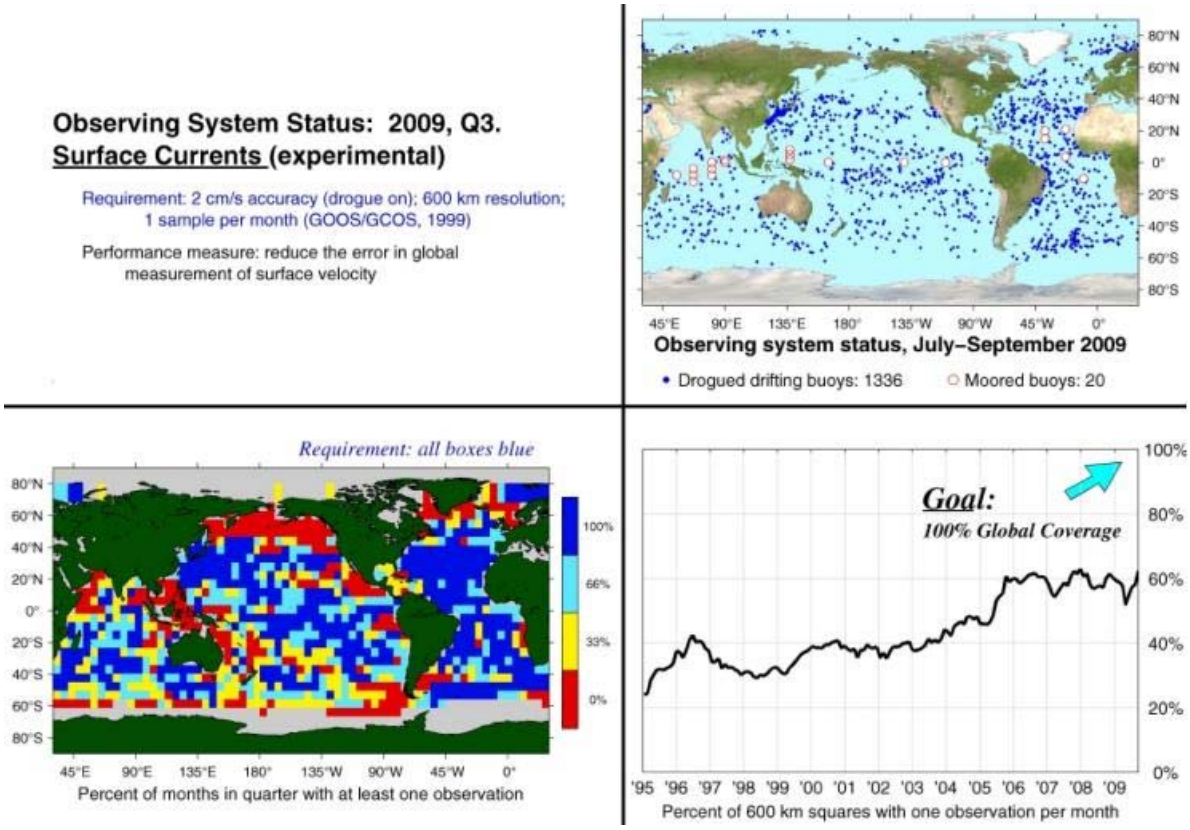


Example for a quarterly report for the heat storage of the mixed layer (the reports are available online at http://www.aoml.noaa.gov/phod/soto/ghs/index.php).

Evaluating the Ocean Observing System: Surface Currents

Rick Lumpkin and Gustavo Goni

The Integrated Ocean Observing System (IOOS) includes an array of moored and drifting buoys that measure near-surface currents throughout the world's oceans. The goal of the project "Evaluating the Ocean Observing System: Surface Currents" is to maintain a quarterly status report that evaluates how well the IOOS satisfied the Global Climate Observing System / Global Ocean Observing System (GOOS/GCOS) 1999 requirement: surface currents should be resolved at 2 cm/s accuracy, with one observation per month, at a spatial resolution of 600 km.



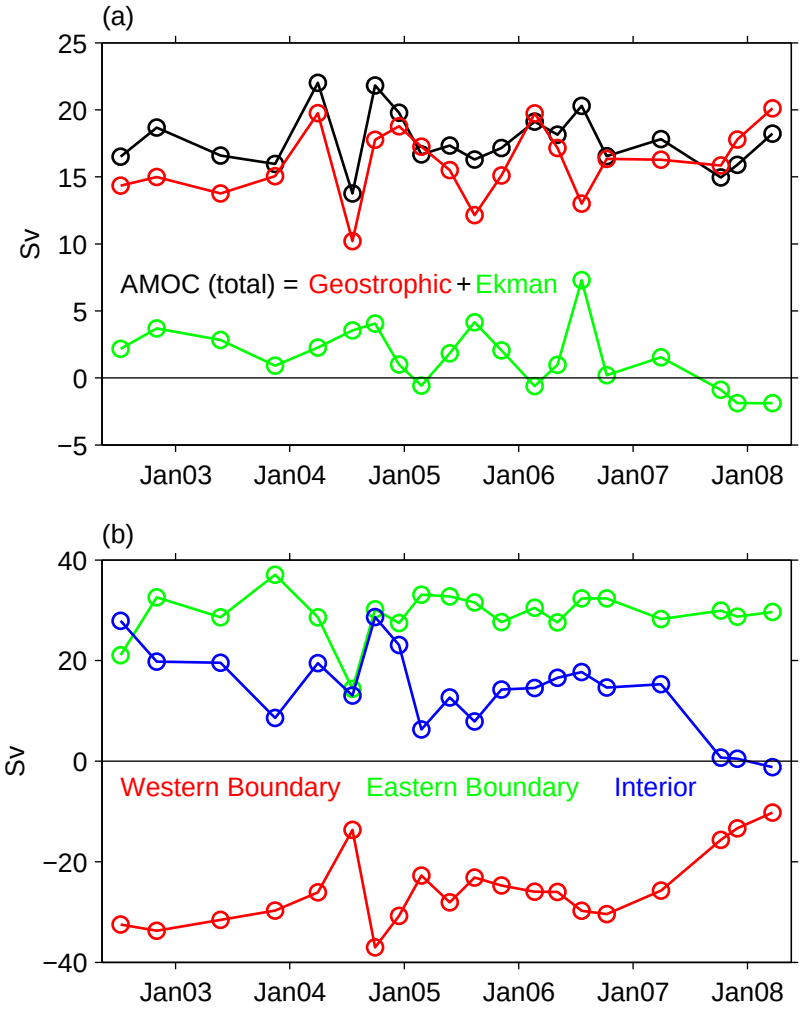
Evaluation of the IOOS for near-surface currents for July—September 2009, showing the distribution of the observations (top right), the spatial distribution of success at meeting GOOS/GCOS 1999 requirements (bottom left), and a time series of the month-by-month fraction of the world's oceans that were measured at the resolution and accuracy stated by these requirements (bottom right).

This project also seeks to quantify the potential bias in surface current fields derived from satellite measurements of sea height and wind, such as NOAA's OSCAR product. In order to separate resolution errors (primarily associated with interpolation of altimetry to gridded fields) from physics-based errors, we are comparing drifter velocities and altimeter-based estimates of geostrophic current speeds where the drifters cross concurrent altimeter tracks (TOPEX, JASON, ERS, etc.). Results indicate that the wind-driven component of drifter motion in some regions, particularly the Southern Ocean, exceeds earlier estimates and must be accounted for with an updated parameterization, and that the eddy kinetic energy levels of satellite-based and in-situ derived current fields must be carefully matched to account for sampling differences.

Evaluating the Ocean Observing System: Quarterly Reports on the Meridional Heat Transport Variability in the Atlantic Ocean

Molly Baringer, Silvia Garzoli and Gustavo Goni

The Meridional Heat transport Program continues the quarterly estimates of the meridional heat transport estimated from the two high-density XBT transects that span the Atlantic. Recent results indicate that the variability of the northward heat transport across nominally 35ºS is significally correlated with the strength of the AMOC, where a 1 Sv increase in the AMOC would yield a 0.055 PW increase in the northward heat transport (Figure). The analysis also shows that both the geostrophic and Ekman transports are important in explaining the variability in the AMOC. Separation of transport into western and eastern boundaries and interior indicates it is critical to monitor all three regions in order to quantify changes in the AMOC and total northward heat transport.

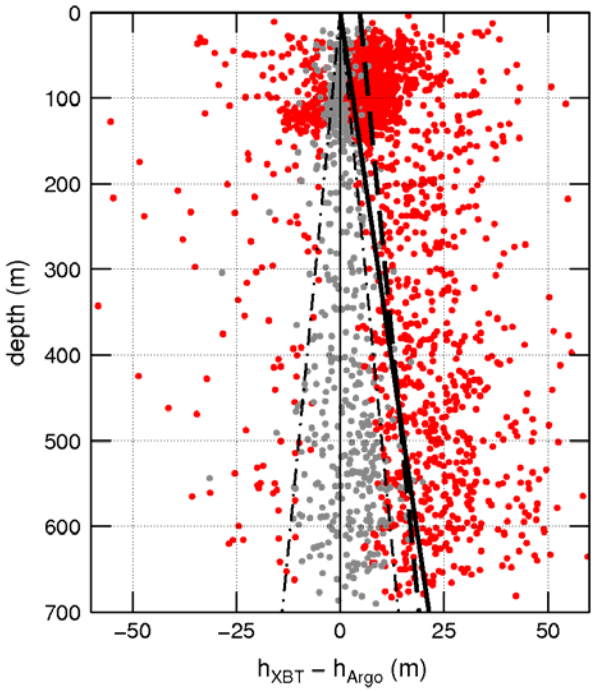


(a) Time series of the AMOC (black) estimated from AX18 and contributions from the geostrophic (red) and Ekman (green) components. (b) Contributions of the western boundary (red), eastern boundary (green), and interior (blue) to the AMOC.

The Expendable Bathythermograph (XBT) Investigation of the Fall Rate Equation

Gustavo Goni and Pedro Di Nezio

Analyses of concurrent the Expendable Bathythermograph (XBT), Conductivity, Temperature, and Depth (CTD) and Argo float observations indicate that there is a systematic difference in temperature profiles, which is likely due to an error in the XBT fall-rate equation. This error has introduced a warm bias in the global XBT data base. AOML is participating with the international community to evaluate these biases and organized a workshop dedicated to discuss the findings related to this issue by different groups. As a consequence, a new fall rate equation may need to be developed and applied to both past and future XBT data. A methodology was developed at AOML to identify and estimate systematic biases between XBT and Argo observations using satellite altimetry. Pseudo-climatological fields of isotherm depths are computed by least squares adjustment of in–situ XBT and Argo data to altimetry–derived sea height anomaly (SHA) data. In regions where the correlations between isotherm depth and SHA are high, this method reduces sampling biases in the in-situ observations by taking advantage of the high temporal and spatial resolution of satellite observations. The increase in XBT minus Argo differences with depth is consistent with known problems in the XBT fall rate equation. Least-squares fit of the depth-dependent XBT minus Argo differences suggest a global 3% bias in the XBT depths with respect to Argo. The depth-dependent 3% error is robust among the different ocean basins confirming that the terminal velocity is a problem in the XBT instruments.

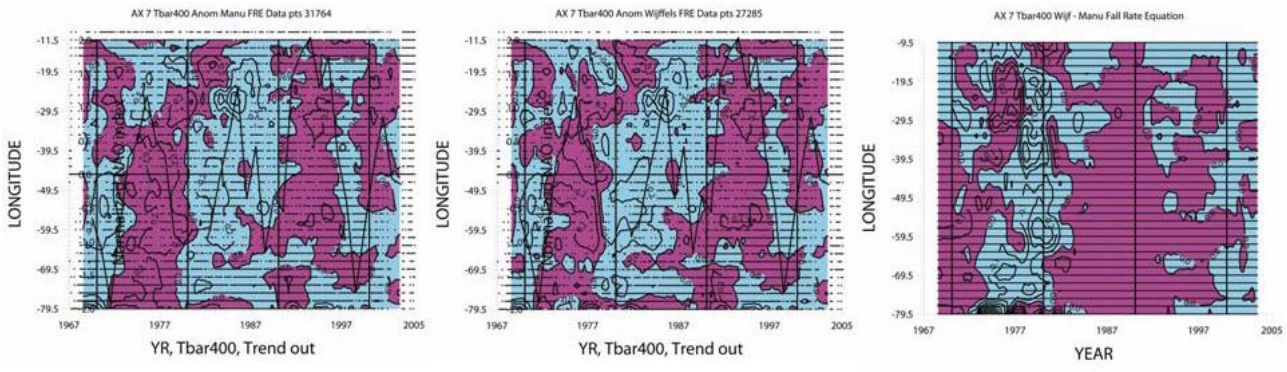


Scatter plot of the differences between the pseudo-climatological isotherm depth estimates as a function of depth for the global ocean. The depth axis corresponds to the pseudo-climatological isotherm depth derived from Argo. Positive $h_{XBT} - h_{Argo}$ differences indicate that the XBT estimates result in deeper isotherms for the period 2000–2007.

Information Content in the Low-Density (LD) Expendable Bathythermograph (XBT) Network in the North Atlantic Ocean

Robert Molinari

The OceanObs99 conference recommended that LD-XBT transects be discontinued after it was shown that the Argo network and satellite altimetry could provide similar information. However, a comprehensive study of the information content in many XBT transects has not been conducted. Some XBT transects provide time series of over 35 years. Therefore, it is important that variability along these transects be estimated to ensure that the few long records of ocean temperature are not ended prematurely. Thus, the basis for this study was to evaluate the information content from LD transects, with initial emphasis on NA decadal variability. However, since the introduction of the XBT it was recognized that the depth of the probe which is not measured directly but from an estimated Fall Rate Equation (FRE) is a major source of uncertainty in XBTs. Other studies completed since the start of this effort have shown these uncertainties are time dependent and give somewhat different results. For example, AX7 zonally bisects the subtropical gyre. The evolution of the upper 400 m temperature anomaly estimated using the manufacturers and a corrected FRE derived by Sussan Wijffels and the difference is shown in the Figure. The Wijffels correction reduces the warming during the late 1970s and thereby produces a larger trend in temperature at 400m than if the manufacturer FRE is used. Thus, before the accuracy of previously completed XBT results could be confirmed, much of the current effort is being directed at an investigation of the FRE. Comparison of different studies has led to the use of the Wijffels corrections in the present effort.



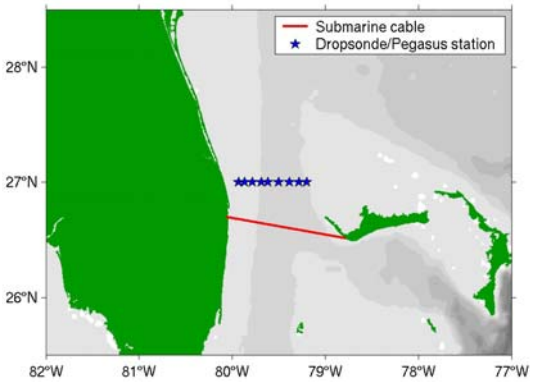
Left Panel: Time-longitude plot of anomalies with respect to the annual cycle of the depth averaged temperature of the upper 400m (degree C) generated from XBT data collected along AX7. Time series were smoothed with a 3-year running mean filter. The manufacturer's fall rate equation was used to compute depth. Center panel: Same as the left panel except the Susan Wijffels corrections to the manufacturer's fall rate equation were used to estimate depth. Right panel: Difference between the left and center panel.

Plots similar to those shown here were completed along the other Atlantic LD transects using the manufacturer FRE. These sections will be recomputed using the Wijffels corrections. The Wijffels results are not expected to be dramatically different from the earlier results except during the late 1970's and early 1980's when the manufacturer and Wijffels FREs exhibit the largest differences. The main difference is expected to be a reduction (but not elimination) of the decadal signal found using the FRE given by the manufacturer. LD transects in the tropical and South Atlantic will then be reviewed. The final components of this study will consider LD transects in the North and Tropical/South Pacific. Interactions with AOML and international investigators to develop a satisfactory correction to XBT depths will continue.

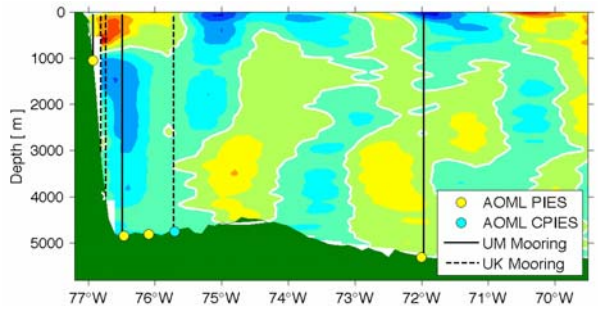
Western Boundary Time Series Program

Molly Baringer, Christopher Meinen and Silvia Garzoli

Climate studies using observational data require long time series in order to capture the interannual and decadal fluctuations associated with climate variability. One of the premier long-term time series for study of the important Atlantic Meridional Overturning Circulation (AMOC) phenomenon is the record of transport and water mass variability in the Florida Current/Gulf Stream and the Deep Western Boundary Current (DWBC) collected as part of the NOAA Western Boundary Time Series (WBTS) program. This program began in 1982 by collecting daily estimates of the Florida Current transport via a submarine cable and via regular shipboard sections near 27°N in the Straits of Florida. In 1984 the program expanded to begin monitoring the DWBC east of the Bahamas along 26.5°N. Some of the technologies used in the intervening 25+ years have changed with time, but this program has produced a critical nearly-continuous time series of ocean transport that is used in validating nearly all ocean models used for study of climate variability. Furthermore the important long records collected by this program have proven invaluable for determining time scales of variability for phenomenon such as the AMOC – the bulk of which is carried in the Florida Current and DWBC at these latitudes. In the present the Florida Current is still monitored using a submarine cable and with routine shipboard measurements, while the DWBC is monitored using a line of four pressure-equipped inverted echo sounders (PIES) and one current-and-pressure-equipped inverted echo sounder (CPIES) along with annual hydrographic cruises. Furthermore the WBTS project has served as the cornerstone of the international RAPID/MOCHA program to measure the basin-wide, full-water-column, transport of the AMOC at 26.5°N using the combination of cable, PIES/CPIES, tall subsurface moorings, and hydrographic sections.



Map indicating the locations of the submarine cable used to make daily estimates of the Florida Current transport. Also shown – the locations of the routine hydrographic and velocity measurements made during routine ship sections.



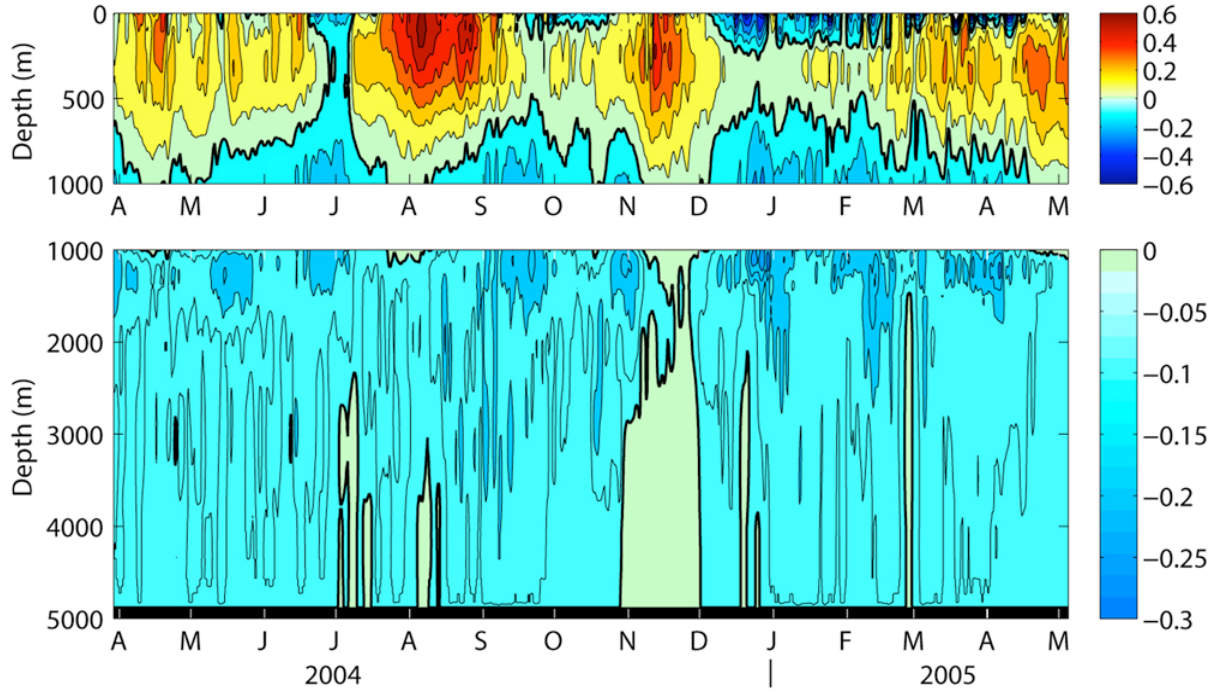
Vertical section illustrating the location and depth of the five PIES/CPIES moorings deployed east of the Bahamas along 26.5°N. Also shown are the locations of the subsurface moorings deployed as part of the RAPID/MOCHA program. Colors are a schematic of the meridional velocity along this line.

Meridional Overturning Circulation and Heat Transport Array / Rapid Watch Climate Change Program

Molly Baringer and Christopher Meinen

"An outstanding problem in the oceanic sciences is the rate of heat and freshwater transport from the equator to the poles, for it is this transport which powers the Earth's weather and climate system." Keffer and Holloway, Nature (1988).

The Meridional Overturning Circulation and Heat-flux Array (MOCHA) is a collaborative project, partnered with the Rapid Watch Climate Change Program (UK RAPID) Program, to measure the meridional overturning circulation (MOC) and ocean heat transport in the North Atlantic Ocean (see figure). These transports are primarily associated with the Thermohaline Circulation. Simply put, warm waters move poleward at the surface of the ocean, where they cool and sink, to return equatorward in the deep ocean. Climate models suggest that the MOC in the Atlantic, and the accompanying oceanic heat flux, vary considerably on interannual time scales. In addition to abrupt climate change scenarios in which the MOC can virtually shut off (Manabe and Stouffer, 1993; Vellinga and Wood, 2002), the "natural" interdecadal variation may range from 20% to 30% of its long-term mean value, according to some models (e.g., Hakkinen, 1999). However, until recently no direct measurement system had been put in place that could provide regular estimates of the meridional overturning circulation to determine its natural variability or to assess these model predictions. Such a system is now deployed along 26.5°N in the Atlantic as part of the joint U.K./U.S. RAPID-MOCHA program, which has been continuously observing the MOC since March 2004 (Figure 1).

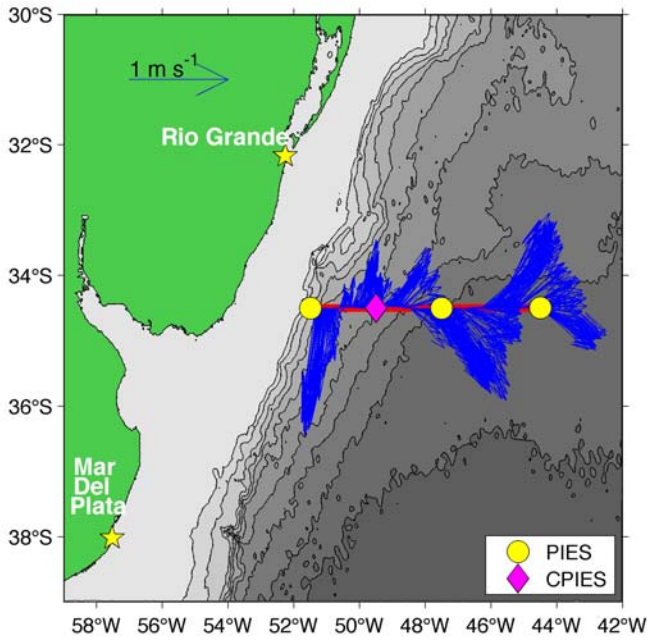


Time series of the transport-per-unit-depth profile (10^5 m^2 s^{-1}) for the region extending from the coast to mooring WB3; the contour interval is decreased in the lower panel to better illustrate the deep variability. A notable reversal in the deep flow occurs during November 2004 (from Johns et al., 2008).

South Atlantic Meridional Overturning Circulation Program

Christopher Meinen, Silvia Garzoli, Molly Baringer and Gustavo Goni

Variations in the Atlantic Meridional Overturning Circulation (AMOC) have been linked to critical climate variables such as precipitation and surface air temperature across the northern hemisphere. The South Atlantic Meridional Overturning Circulation Program (SAM), which began in 2009, seeks to capture key components of the AMOC in a hitherto under-sampled region - the South Atlantic Ocean. Numerical climate models have indicated that important water mass transformations are undergone by the AMOC flows in the South Atlantic, however little data has previously been available for the study of these flows. The initial array deployed as part of the SAM project involves a zonal line of three pressure-equipped inverted echo sounders (PIES) and one current-and-pressure-equipped inverted echo sounder (CPIES) deployed near the western boundary at 34.5°S. Data from these instruments will be used to monitor the Brazil Current and the Deep Western Boundary Current as they carry components of the AMOC along the western boundary of the basin. Coupled with annual or semiannual hydrographic observations collected on an Argentine or Brazilian research vessel, these data will produce better understanding of the processes involved in AMOC variability in the South Atlantic. The SAM array is funded by the NOAA Office of Climate Observations and is a collaboration between AOML-PHOD and scientists in Brazil and Argentina. Additional collaborations with the French, German and South African 'Good Hope' program will allow the SAM observations to provide the first continuous time series observations of basin-wide AMOC flows.



Map indicating the locations of the four PIES/CPIES instruments deployed as part of the SAM project. Also shown (blue arrows) are the near-surface velocities observed by the shipboard-ADCP onboard the Brazilian Navy research vessel Cruzeiro do Sul during the March 2009 deployment cruise.

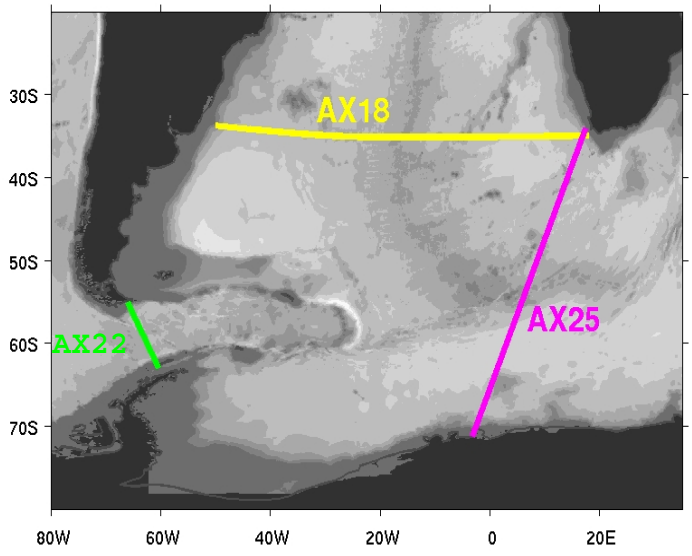
Atlantic Meridional Overturning Circulation Variability in the South Atlantic and Importance of Inter-Ocean Exchanges

Shenfu Dong, Silvia Garzoli, Molly Baringer, Christopher Meinen and Gustavo Goni

The main objectives of this study are to assemble and analyze historical in situ and satellite data sets with an aim towards understanding the inter-ocean exchanges, to evaluate the correlation between the Atlantic Meridional Overturning Circulation (AMOC) strength and the meridional heat transport, and to investigate the predictability of the AMOC through the improvement of our understanding of the mechanisms of the AMOC variability in the South Atlantic using available observations and numerical simulation.

The study region is focused on the South Atlantic in a box bounded by three XBT transects at 35ºS (AX18), across the Drake Passage (AX22), and south of Africa (AX25). The analysis of the AX18 measurements suggested that the variability of the northward heat transport across AX18 is significantly correlated with the strength of the AMOC, where a 1 Sv increase in the AMOC would yield a 0.05 PW increase in the northward heat transport. The XBT measurements across the Drake Passage and south of Africa are used to examine the transport from the Pacific and Indian Oceans into the South Atlantic, and to investigate their relationship to the northward heat transport and the AMOC variability at 35ºS with the aim of defining the importance of variations in inter-ocean exchanges and improving our understanding of the mechanisms of the AMOC variability in the South Atlantic.

This project examines the changes in oceanic heat content and air-sea heat fluxes in the study region, and investigates their relationship with the northward heat transport across 35ºS, as well as their relationship with the transport across the Drake Passage and that across south of Africa. In order to extend the time series to the altimeter period (1993 – present) and get a better temporal resolution for future studies, we are exploring potential methodologies to approximate the transport from altimeter sea surface height measurements.

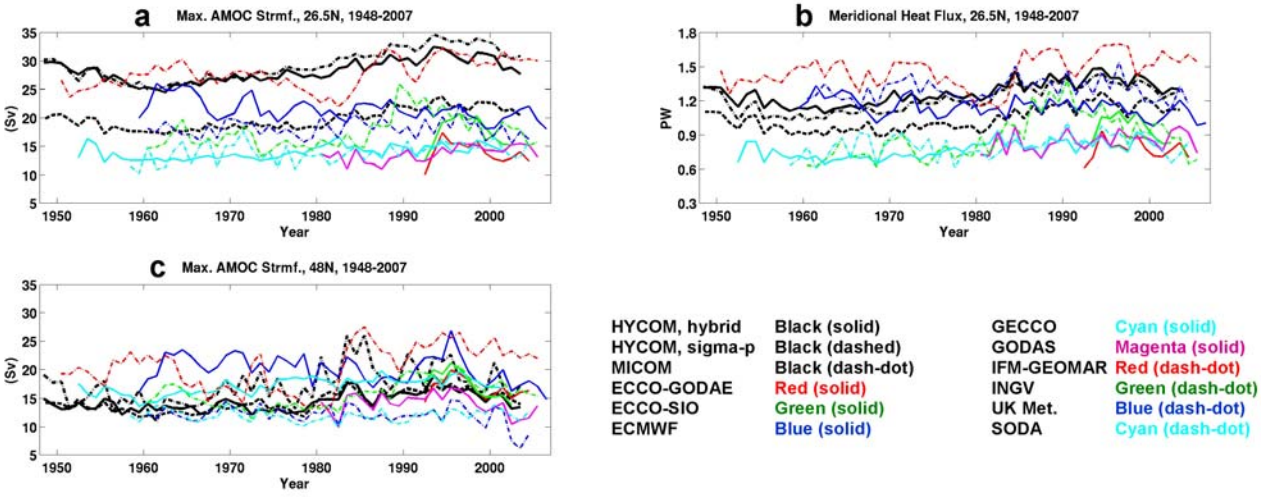


Locations of the XBT transects (AX18, AX22, and AX25) in the South Atlantic region.

Observing System Simulation Experiments for the Atlantic Meridional Overturning Circulation

George Halliwell and Carlisle Thacker

The long-term objective of this project is to design optimal observing system strategies to monitor changes in the Atlantic Meridional Overturning Circulation (AMOC), particularly changes that are potentially related to rapid climate change. The strategies include developing the capability of performing Observing System Simulation Experiments (OSSEs) and Observing System Experiments (OSEs) at NOAA/AOML and then using these systems to perform observing system design studies. They also include performance of "virtual OSSEs" to conduct preliminary assessments of AMOC observing strategies while the full OSSE system is under development. Development and validation of the full OSSE capability at AOML will occur over the next 1-2 years. In the meantime, early efforts have focused in part on virtual OSSEs because the expected error reduction due to a new set of observations can be quantified without actually performing data assimilative model runs. We are using multi-model ensembles of simulations (Figure) to estimate the error covariances required for both classical and virtual OSSEs. These models include three HYCOM runs performed at AOML plus nine publicly-available models. The representation of AMOC transport and the associated meridional heat flux (Figure) displays large scatter, demonstrating large uncertainties in present-day ocean models. This will make it difficult to produce suitable nature runs required to perform classical OSSEs. Nature run production will therefore be a major effort over the next 1-2 years.

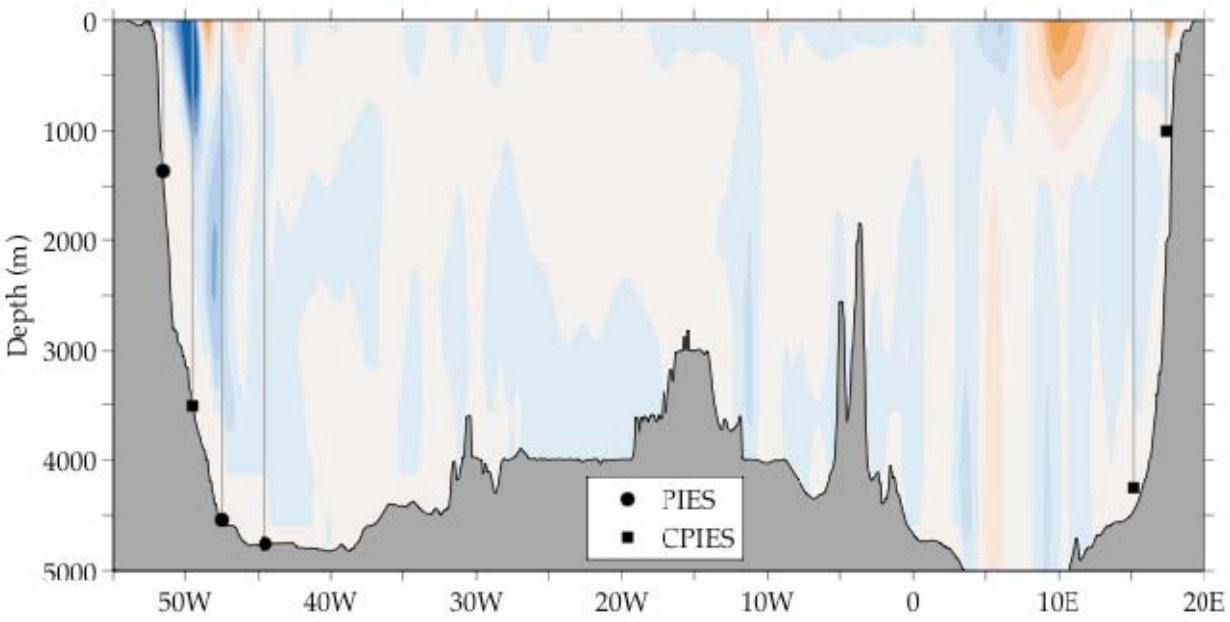


AMOC transport (maximum AMOC streamfunction) at 26.5°N (a) and at 48°N (c) along with meridional heat flux at 26.5°N (b) from all 12 models listed in the legend. The first three models listed were performed using the HYCOM modeling system at AOML, and they substantially reproduced the large differences in AMOC transport and heat flux that are observed in the other models.

Observability of the Meridional Overturning Circulation in the South Atlantic Ocean

Renellys Perez and Silvia Garzoli

In this project it is proposed to conduct a multi-model analysis to determine the optimal location and minimum requirements for a monitoring system designed to measure the Meridional Overturning Circulation (MOC) in the South Atlantic Ocean. The proposed work will evaluate the MOC as reproduced in three high-resolution (eddy permitting to eddy resolving) ocean general circulation models chosen for their skill at simulating boundary currents in the South Atlantic. These ocean models include the Parallel Ocean Circulation Model (POCM), an implementation of the Ocean PArallelise model (DRAKKAR), and the Ocean general circulation model For the Earth Simulator (OFES). The main objectives will be to estimate the scales of MOC variability and test the representativeness of any sampling array designed to monitor the MOC in the South Atlantic. Five different array configurations will be tested ranging from direct current measurements (a simple subsampling of the model velocity fields) to indirect current measurements derived from density profiles (either from direct temperature and salinity measurements or inferred from inverted echo sounder travel times). Further analysis will examine whether additional parameters, such as sea level anomalies in the eastern and western boundary currents or estimates of volume and or heat transports through the Drake Passage and Agulhas Retroflection, can be used to increase the ability of these array configurations to reproduce the MOC signal. Results from this analysis will provide guidance for the design of an "optimized" South Atlantic MOC (SAMOC) monitoring system, and additionally address whether a pilot array deployed along 34.5˚S can be incorporated into a SAMOC monitoring system (Figure).



Zonal-vertical section along 34.5°S of mean meridional velocity from the POCM simulation with the location of the pilot array instruments overlaid.

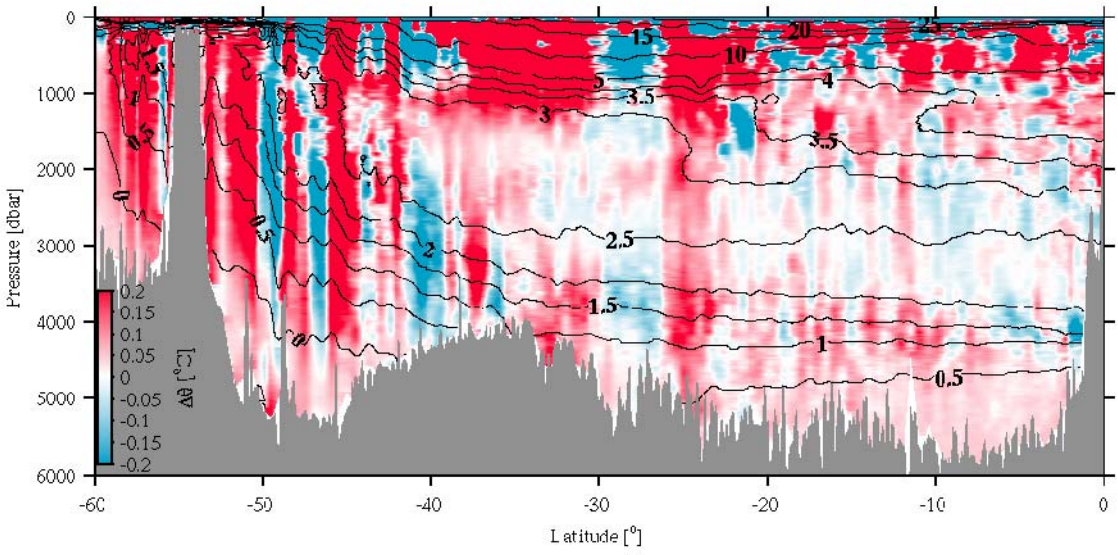
CLIVAR Repeat Hydrography/CO_2 Inventories

Molly Baringer, Rick Wanninkhof and Jia-Zhong Zhang

This program aims to reoccupy selected trans-basin sections previously occupied over the last 50 years to document changes in heat, fresh water, carbon, nutrients, and oxygen and trace gases in the ocean. Sections, selected based on their historical record and geographic importance for capturing ocean circulation features, are occupied by NOAA and NSF investigators with the aim of approximately decadal repeats along each line. Despite numerous technological advances over the last several decades, ship-based hydrography remains the only method for obtaining high-quality, high spatial and vertical resolution measurements of a suite of physical, chemical, and biological parameters over the full water column.

Ship-based hydrography is essential for documenting ocean changes throughout the water column, especially for the deep ocean below 2 km (52% of global ocean volume). Hydrographic measurements are needed to:

- reduce uncertainties in global freshwater, heat, property and sea-level budgets,
- determine the distributions and controls of natural and anthropogenic carbon (both organic and inorganic),
- determine ocean ventilation and circulation pathways and rates using chemical tracers,
- determine the variability and controls in water mass properties and ventilation,
- determine the significance of a wide range of biogeochemically and ecologically important properties in the ocean interior, and
- maintain the historical database of full water column observations necessary for the study of long-timescale changes (e.g. Figure).

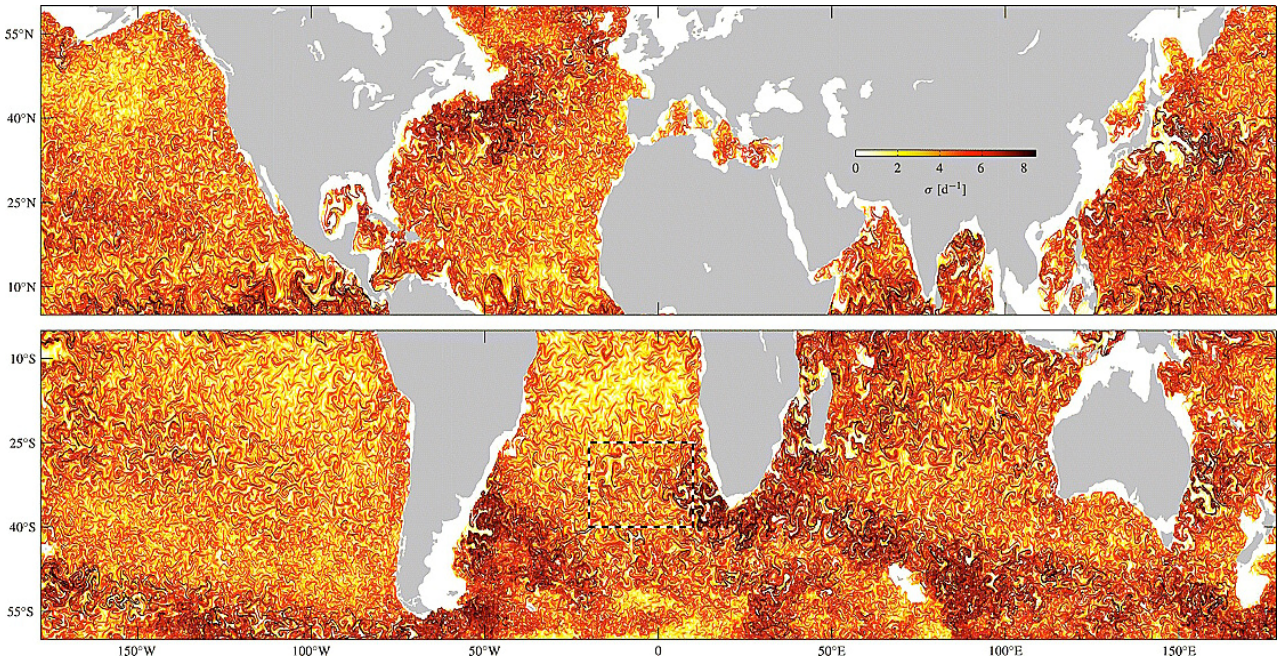


Potential temperature differences (red warm, blue cold) of the 2005 – 1989 occupations of A16S meridional section sampling the western basins of the South Atlantic. Mean isotherms from the two cruises are contoured (black lines) at 0.5 ℃ intervals below 5 ℃, and 5 ℃ intervals above. Note the warming of cold waters throughout the Scotia Sea (south of 53 ℃), and the warming of bottom waters deeper than about 3500 dbar throughout the Argentine and Brazil Basins to the north. Figure follows Johnson and Doney (2006).

Lagrangian Coherent Structures in the Ocean

Gustavo Goni and Pedro DiNezio

Supported by NASA funding and together with F. Beron-Vera and J. Olascoaga, scientists at the University of Miami, the feasibility of using dynamical systems tools to unambiguously identify mesoscale oceanic eddies from surface ocean currents derived using climatological hydrography and altimetry is being investigated. Specifically, the analysis is based on extracting Lagrangian coherent structures (LCSs) from finite-time Lyapunov exponent (FTLE) fields. The FTLE fields reveal with unprecedented detail an intricate tangle of LCSs, which are hidden in ocean surface topography maps but sometimes are apparent in ocean color images. These LCSs delineate fluid domains with very different advective properties, and thus their detection provides an objective (i.e., frame-independent) means of identifying eddy boundaries. The importance of this work lies in considering LCSs in quantifying transport by eddies. Such a quantification does not rely on the common assumption—which is shown to be sometimes not valid—that transport is largely effected by the trapping and subsequent translation of water slugs inside eddies defined as the regions enclosed by sea height contours within which rotation dominates over strain. LCSs are calculated globally and compared with satellite-tracked drogue drifter trajectories within a selected region of the South Atlantic.



A global snapshot of backward-time FTLE field on 20 April 2005 computed using sea surface velocities inferred from climatological hydrography and altimetry. LCSs roughly correspond to regions of most intense red tones.

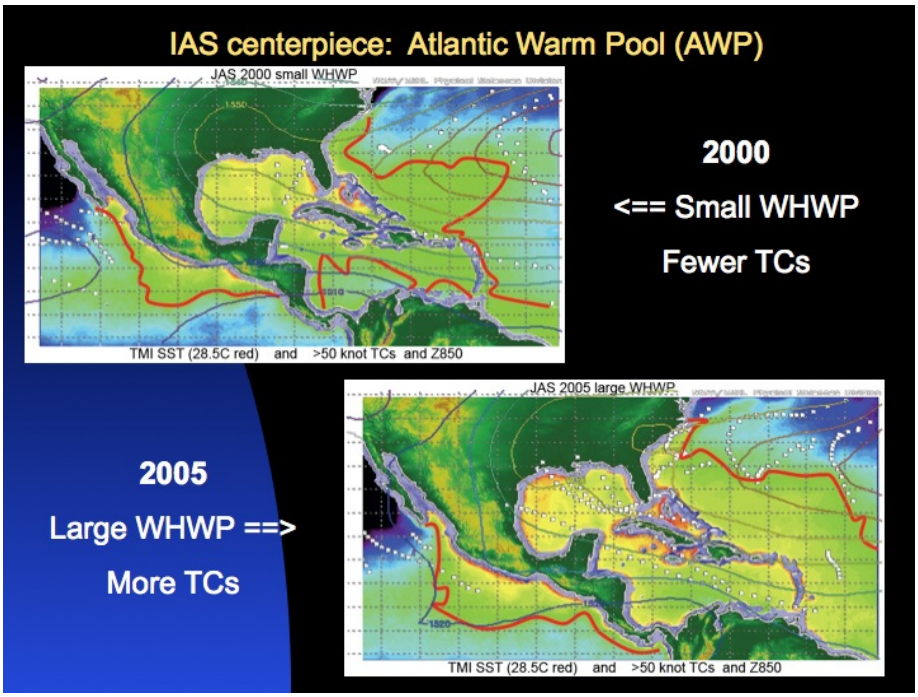
Intra-American Study of Climate Processes

David Enfield

The Intra-American Study of Climate Processes (IASCLIP) is proposed for 2009-2014, as a new component of CLIVAR VAMOS. The geographic milieu of IASCLIP is the Western Hemisphere warm pool (WHWP) comprised of the Caribbean and Gulf of Mexico, the eastern North Pacific warm waters off the Pacific coast of Central America and the western tropical Atlantic immediately east of the Lesser Antilles, including the islands and land regions in and around the WHWP. The overarching goal of IASCLIP is to estimate and exploit potential predictability of warm-season weather and climate in the region, mainly on intraseasonal to interannual timescales, based on improved understanding and modeling of relevant physical and dynamical processes. IASCLIP will also seek to link research to societal applications in the region.

Almost yearly, extreme weather and climate events cause damage to economies in the Western Hemisphere mounting in the millions, sometime billions of US dollars, and they occur most often during summer in the form of tornadoes, floods, droughts and tropical cyclones. There is mounting evidence that summer climate depends on both the Pacific and Atlantic influences together. The WHWP is the boreal summer heating center for the Western Hemisphere; it is responsible for funneling moisture to all the surrounding regions during that season, and controls the summer environment for Atlantic hurricanes.

By orchestrating the efforts of scientists in the U.S., Mexico, Caribbean and Central/South American countries over the 2009-2014 time period, IASCLIP aims to: (1) Promote, coordinate, and organize research activities that aim to understand better the climate and hydrological processes in the IAS region, (2) Improve our ability to represent these processes in global climate models and predict them on subseasonal to interannual timescales, and (3) Facilitate applications of climate forecast products in the IAS region.

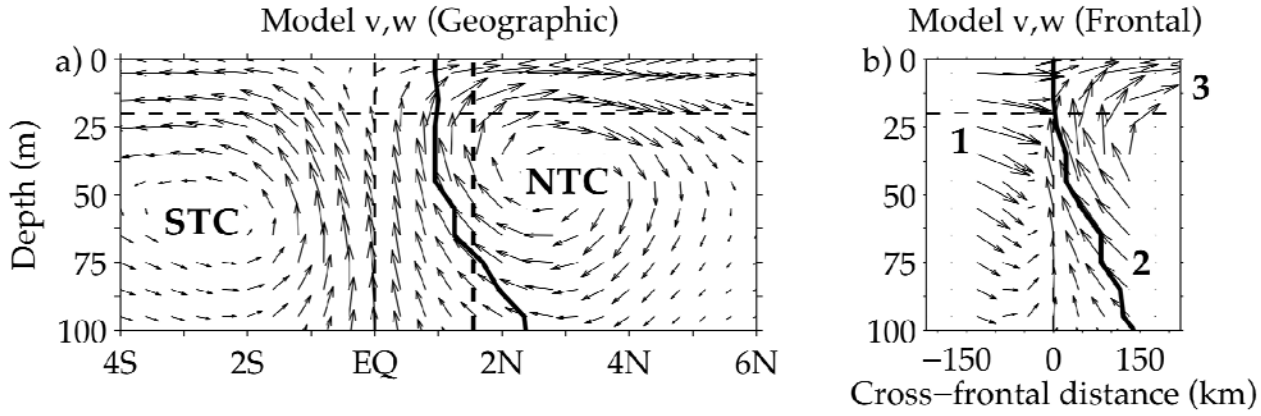


The tropical Atlantic SST varies in proportion to the size of the pool of water greater than about 28°C (red contour). Climate impacts accrue as well, the example shown here being the number of tropical cyclone tracks in a hurricane season. Upper left: smaller warm pool (2000) and fewer storm tracks (small dots). Lower right: larger warm pool (2005) and more storm tracks.

Simulation Experiments for the Pacific Upwelling and Mixing Physics Study

Renellys Perez

Nearly two-decades of shipboard Acoustic Doppler Current Profiler measurements along 140W and 125W and an ocean model are used to describe the mean structure of meridional-vertical tropical cells (TCs) in the central equatorial Pacific. The northern cold tongue front is perturbed by tropical instability waves (TIWs) and averaging the flow in geographic coordinates leads to a mixing up of important frontal processes. Hence, velocities are also averaged in a coordinate system centered on the instantaneous position of the northern front. When averaged in geographic coordinates, the observed and simulated TCs are equatorially-asymmetric with larger meridional and vertical velocities north of the equator (Figure 1a). Surface poleward flow and subsurface equatorward flow increase across the mean position of the front with strong off-equatorial downwelling near 4N. In frontal coordinates, both observations and model provide evidence of a mean secondary circulation. In the model, this secondary circulation is characterized by cold tongue water that moves northwards toward the front in the surface mixed layer and downwells south of the front in panel b of the figure. North of the front, water below the surface mixed layer moves southward towards the front in panel b of the figure, upwells, and then moves northward in the surface mixed layer in panel b of the figure. Net convergence (downwelling) on the cold side of the front is due to an imbalance between convergence and divergence on the western and eastern side of the TIW cusps, respectively. The observed secondary circulation is shifted northwards relative to the front by approximately 100 km, and frontal convergence was found on the western and eastern sides of the TIW cusps.

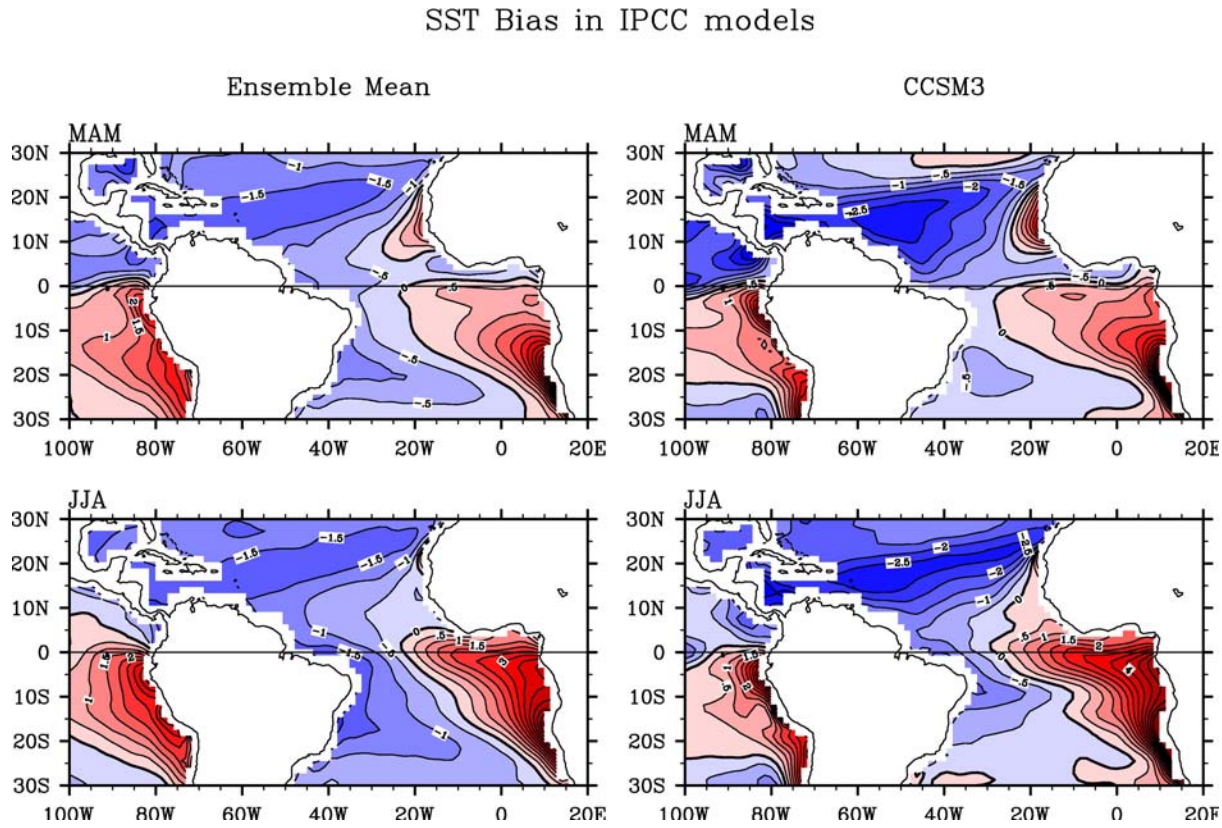


Model mean meridional and vertical velocity structure. Panels compare zonally and temporally-averaged velocity vectors in a) geographic and b) frontal coordinates at the central meridians. Frontal means are plotted relative to the mean position of front (thick dashed line). Thick solid line corresponds to maximum mean temperature gradient. Labels STC and NTC identify southern and northern TCs, respectively. Labels 1, 2, 3 identify components of the secondary circulation associated with the front.

The Tropical Atlantic Sea Surface Temperature Bias in Coupled General Circulation Models

Sang-Ki Lee, Chunzai Wang and David Enfield

Despite our growing recognition for the important role of tropical Atlantic atmosphere-ocean processes on climate variability, almost all of the state-of-the-art atmosphere-ocean coupled climate models cannot reproduce the annual cycle of tropical Atlantic Sea Surface Temperature (SSTs). Due to this shortcoming in the climate models, currently we do not have a skill to simulate the tropical Atlantic climate variability. The overall goal of this project is to identify processes and/or parameterizations in the coupled models that are responsible for generating tropical Atlantic SST biases. With this goal in mind, we will analyze the mixed layer heat budget of a major coupled model to identify the heat budget terms that contribute significantly to the tropical Atlantic SST bias. One of our primary interests is to examine the possible role of local ocean dynamics on the SST bias in three key regions, namely the southeastern Atlantic Ocean, the eastern and central equatorial Atlantic Ocean, and the tropical North Atlantic Ocean. We will also determine and quantify the external influences and work to understand if and how local atmosphere-ocean feedback processes amplify the remote signals. These questions will be addressed by carefully designing numerical model experiments using the NCAR community climate system model version 3 (CCSM3).

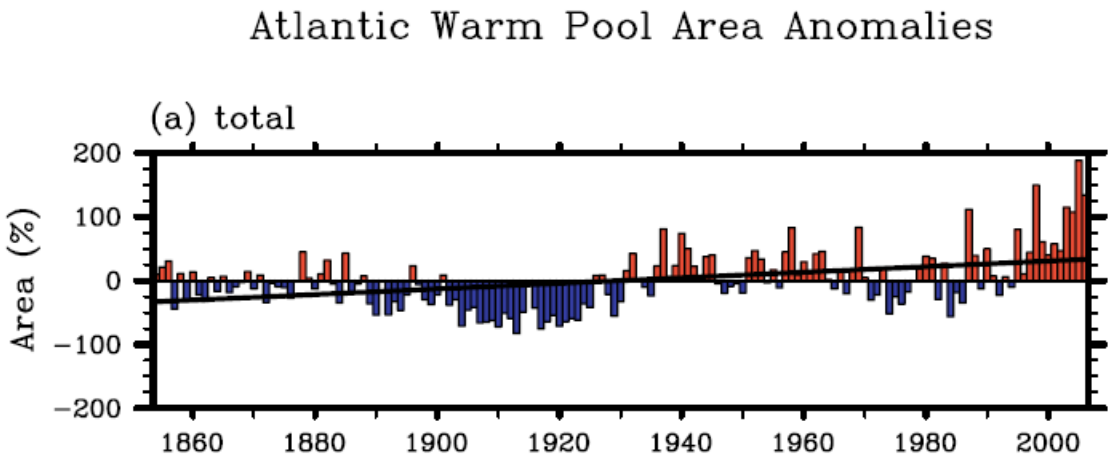


The tropical Atlantic SST bias (simulated - observed) of IPCC models during boreal spring (upper panels) and summer (lower panels). The left column is from the ensemble average of IPCC models and the right column is from CCSM3. The total of twelve IPCC models are used to construct the ensemble mean. All IPCC model data are obtained from "the climate of 20th century" scenario. ERSST2 for the same period (1870-1999) is used for the observation.

Improving Predictability of the Atlantic Warm Pool in Ocean Model for Assistance to Operational Hurricane Forecast

Chunzai Wang and Sang-Ki Lee

Both observational and modeling studies have shown that the Atlantic warm pool (AWP) affects Atlantic Tropical Cyclones (TCs) in multiple ways. Therefore, improving the simulations of the AWP during the hurricane season in NCEP/EMC operational models will contribute to improving the forecast of the intensification, formation and track of Atlantic hurricanes. In this Joint Hurricane Testbed (JHT) project, we will focus on improving predictability of the AWP and associated mesoscale ocean features for transition to operational hurricane forecast using HYbrid Coordinate Ocean Model (HYCOM), which is the ocean model component of Hurricane Weather Research and Forecast (HWRF)-HYCOM, an experimental hurricane forecast system at NCEP/EMC. Our ultimate goal is to evaluate and improve HYCOM's predictability of the AWP and associated mesoscale ocean features for NCEP/EMC transition to operational hurricane forecast.

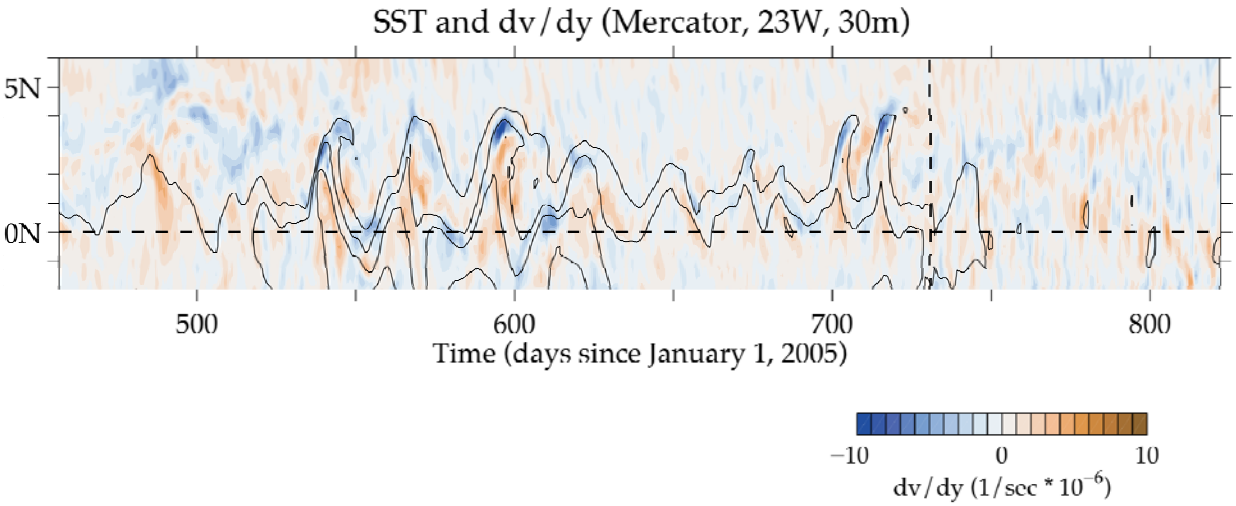


AWP area anomaly indices (%) during the Atlantic hurricane season of June–November (JJASON). The area index is calculated as the anomalies of the area of SST warmer than 28.5ºC divided by the climatologicalJJASON AWP area.

Evaluation of the Three-Dimensional structure of Temperature, Salinity, and Velocity in the Central Equatorial Atlantic

Renellys Perez and Rick Lumpkin

The cross-equatorial structure of zonal currents in the central equatorial Atlantic have been described by observations, but much less is known about the structure of the meridional and vertical currents. These currents play an important role in the cold tongue surface mixed layer heat balance, and must be better represented in ocean models and coupled climate models. Daily averages from the high-resolution (0.25 degree longitude x 0.25 degree latitude x 50 vertical level) MERCATOR global ocean analysis product are used to study the three-dimensional upper-ocean circulation in the central equatorial Atlantic during the 2005-2009 tropical instability wave seasons. The equatorial circulation is dramatically modified by tropical instability waves (Figure 3), and averaging the flow in geographic coordinates leads to a mixing up of important frontal processes. Hence, velocities are also studied in a coordinate system centered on the instantaneous position of the northern cold tongue front. We explore whether there is evidence of a mean secondary circulation at the northern front, and how tropical instability waves are connected to that secondary circulation. Current measurements obtained from shipboard ADCP transects, drifters, and PIRATA/PNE moorings are used to validate the simulated currents.



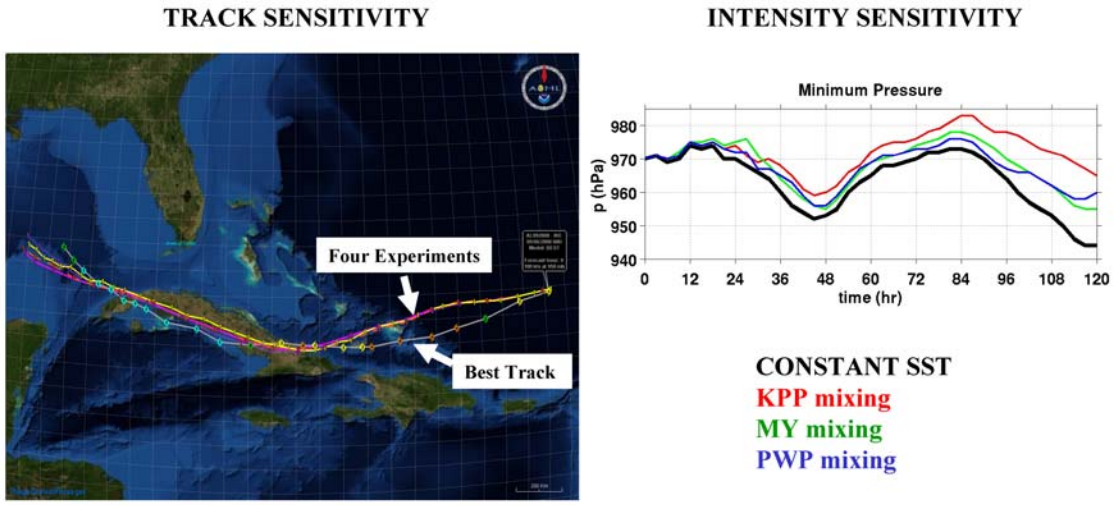
Meridional-temporal structure of the MERCATOR PSY3V1 near-surface divergence of meridional velocity along 23W during 2006-2007 TIW seasons.

Ocean Model Evaluation and Improvement in the NOAA/AOML/HRD HWRF-X

Experimental Tropical Cyclone Forecast Model

George Halliwell and AOML Hurricane modeling group

This project employs the ocean modeling expertise of PhOD in collaboration with the NOAA/AOML/HRD coupled modeling group to improve the performance of coupled hurricane forecast models as part of the Hurricane Forecast Improvement Project (HFIP). Accurate intensity forecasts require that the coupled model accurately forecast the cooling rate of sea surface temperature (SST) beneath the storm. The ocean model must therefore accurately forecast the deepening and entrainment cooling of the ocean surface mixed layer. A one-dimensional version of the HYbrid Coordinate Ocean Model (HYCOM) has been coupled to the multiple-nest experimental Hurricane Weather Forecast Model (HWRF-X) of HRD. Initial tests conducted at low resolution (27/9 km) with a highly idealized ocean initialization have demonstrated that the ocean model performs well. HYCOM contains multiple vertical mixing parameterizations which impact the rate of SST cooling. Track and intensity forecasts obtained from three runs that use different vertical mixing choices and one run where initial SST is held constant demonstrate small track forecast sensitivity but potentially significant intensity sensitivity (Figure). Future work will compare forecasts that use the 1-D and 3-D versions of HYCOM to assess the impact of three-dimensional ocean dynamics. A major effort is also underway to evaluate and improve ocean model initialization, which has a large impact on the forecast rate of SST cooling no matter which vertical mixing scheme is chosen.

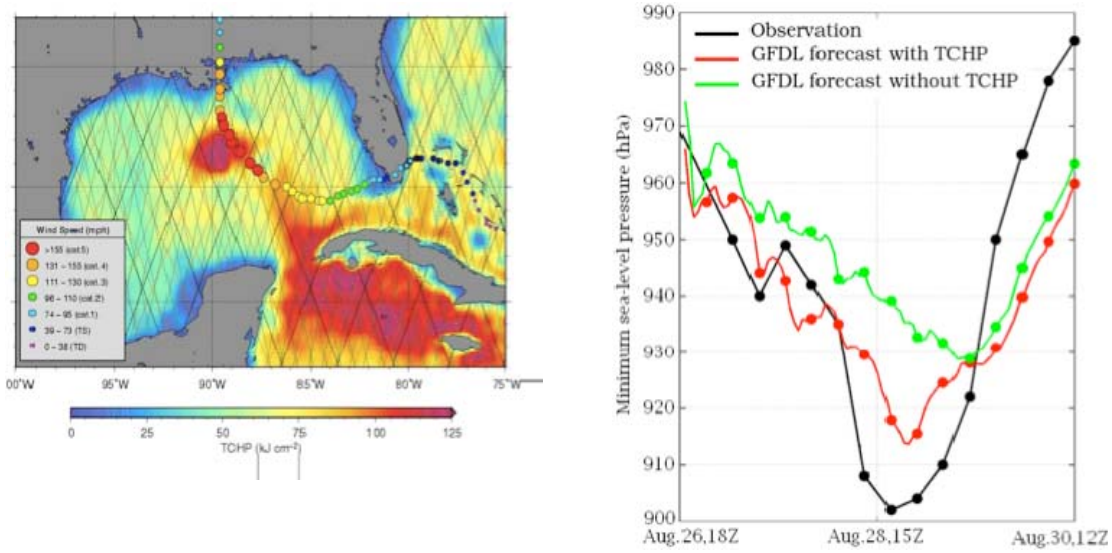


Impact of vertical mixing parameterization (through SST cooling) on four tests of the HWRF-X hurricane forecast model coupled to a one-dimensional version of HYCOM. The four forecasts (legend) include no ocean model (constant SST) plus three cases using different vertical mixing schemes: K-Profile Parameterization (KPP), Mellor-Yamada level 2.5 turbulence closure, and the Price-Weller-Pinkel (PWP) Dynamical Instability Model. The left panel illustrates the relatively small sensitivity of a 5-day track forecast for Hurricane Ike (2008) while the right panel displays the larger sensitivity of forecast intensity as illustrated by minimum central atmospheric pressure. As expected, the strongest intensity is achieved in the case with no SST cooling.

Tropical Cyclone Heat Potential

Gustavo Goni, Joaquin Trinanes and Prdro Di Nezio

Sudden tropical cyclone (TC) intensification has been linked with high values of upper ocean heat content contained in mesoscale features particularly warm ocean eddies, provided that atmospheric conditions are also favorable. Tropical cyclones occur in seven ocean basins: tropical Atlantic, northeast Pacific, northwest Pacific, southwest Indian, north Indian, southeast Indian, and south Pacific. The intensification of TCs is very complex with influences from TC dynamics, upper ocean interaction, and atmosphere circulation. In general, the accuracy of TC intensity forecast has lagged behind TC track forecasts because of the complexity of the problem and because many of the errors introduced in the track forecast are translated into the intensity forecast (DeMaria *et al.*, 2005). The importance of the ocean thermal structure in TC intensification was first recognized by Leipper and Volgenau (1972). While sea surface temperature (SST) plays a role in the genesis of TCs, the ocean heat content (OHC) contained between the sea surface and the depth of the 26°C isotherm (D26), also referred as Tropical Cyclone Heat Potential (TCHP), has been shown to play a more important role in TC intensity changes (Shay *et al.*, 2000). The TCHP shows high spatial and temporal variability associated with oceanic mesoscale features. TC intensification has been linked with high values of TCHP contained in these mesoscale features; particularly warm ocean eddies, provided that atmospheric conditions are also favorable. Since sustained *in situ* ocean observations alone cannot resolve global mesoscale features and their vertical thermal structure, different indirect approaches and techniques are used to estimate the TCHP. Most of these techniques use sea surface height observations derived from satellite altimetry, a parameter that provides information on the upper ocean dynamics and vertical thermal structure. AOML posts real-time fields of TCHP at: http://www.aoml.noaa.gov/phod/cyclone/data/

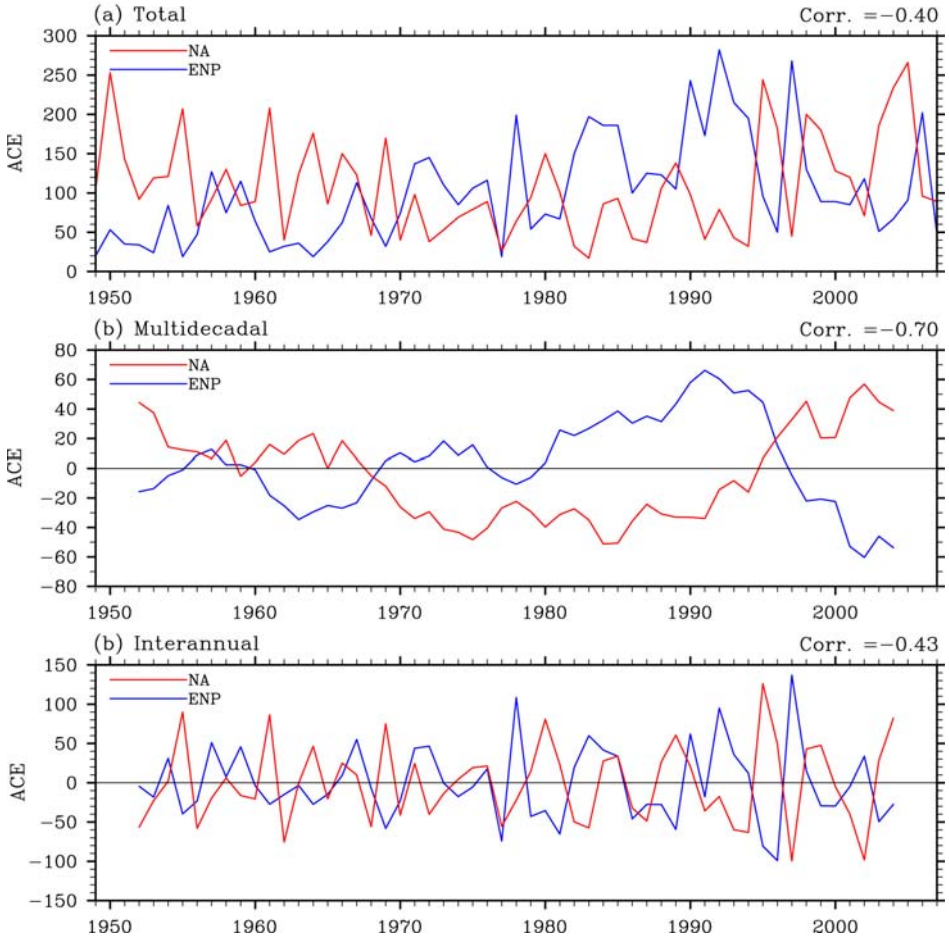


(left) Track of Hurricane Katrina (2005) in the Gulf of Mexico superimposed to the altimetry-derived tropical cyclone heat potential field. The path of this TC shows an intensification when the hurricane travelled over a warm ring. (right) Minimum atmospheric pressure at sea level during the passage of hurricane Katrina in the Gulf of Mexico in 2005; showing the actual observations (black), and the reduction of error in the GFDL model output with (red) and without (green) initializing the model with the TCHP produced at NOAA National Hurricane Center

Climate Changes and Atlantic Hurricane Activity

Chunzai Wang and Sang-Ki Lee

Atlantic tropical cyclone or hurricane activity has been shown to have a large variability on different timescales. In particular, Atlantic hurricane activity is largely increased in frequency and intensity from 1995-2005, but its activity is then near or below normal in the past few years of 2006-2009. The increase in Atlantic hurricane activity has fueled a debate on the role of global warming and natural climate variability in the increase. Improving the understanding of climate changes and their impact on hurricanes is both scientifically and socially important. Using both observational data and numerical models, AOML's scientists investigate climate variability, large-scale atmospheric and oceanic circulation and their impact on hurricane activity. Major goals are to (1) understand how and why global ocean warming affects Atlantic hurricane activity; (2) improve the understanding of natural climate variability influences on hurricane activity such as ENSO, Pacific decadal oscillation, Atlantic multidecadal oscillation and Atlantic warm pool; (3) investigate the relative role of the tropical oceans in affecting Atlantic hurricane activity; and (4) investigate the relationship between tropical cyclones in the North Atlantic and the eastern North Pacific and associated mechanisms.

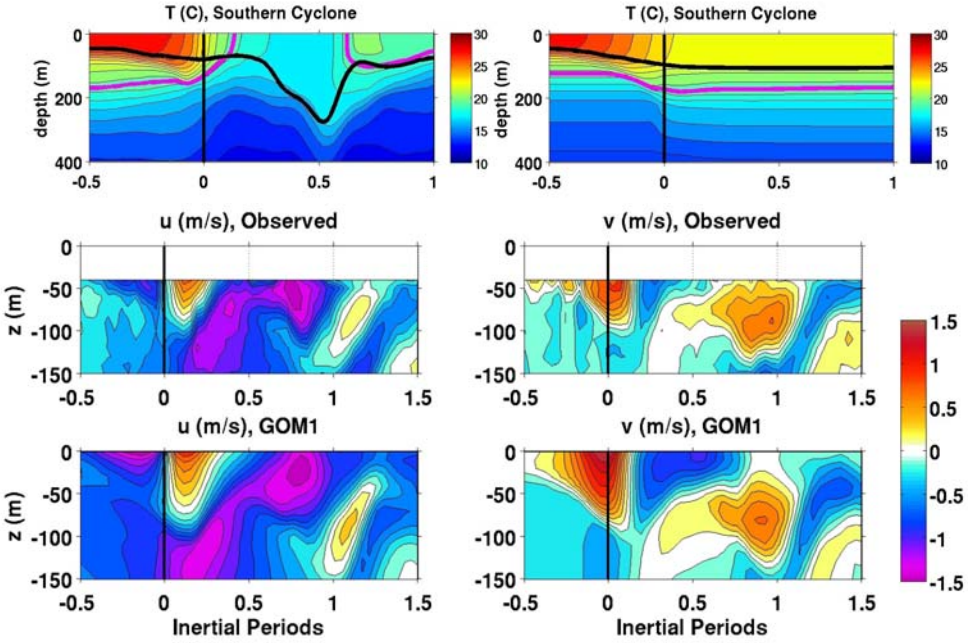


Time series of accumulated cyclone energy (ACE; 10^4 kt^2) in the North Atlantic (NA) and eastern North Pacific (ENP) from 1949-2007. ACE is a common measure used to express tropical cyclone activity.

Evaluation and Improvement of Ocean Model Parameterizations for NCEP Operations

George Halliwell

The primary objective of this project is to evaluate and improve ocean model parameterizations in NOAA National Center for Environmental Prediction (NCEP) coupled hurricane forecast models in collaboration with the NOAA National Hurricane Center (NHC) and NOAA/NCEP Environmental Modeling Center (EMC). The primary strategy is to initialize the Hybrid Coordinate Ocean Model (HYCOM) with realistic ocean conditions, force it with realistic atmospheric fields, and then evaluate model performance against high-quality ocean observations, emphasizing the impact of vertical resolution, horizontal resolution, vertical mixing, air-sea flux parameterizations (drag coefficients), ocean dynamics, and the accuracy of the ocean initialization. It is funded by the USWRP Joint Hurricane Testbed program. The model evaluation completed to date has focused on hurricane Ivan in the GOM, where high-quality *in-situ* moored current measurements have been acquired, focusing on the impact on the ocean response of the Loop Current (LC) and associated warm and cold eddies, along with the complex bathymetry of the continental shelf/slope region. Objectively analyzed fields from multiple space-based platform data such as radar altimeter measurements and SST fields are also used in the evaluation. Analyses of the ocean response to hurricanes Katrina and Rita are now underway. Aspects of the results obtained to date are presented in the figure. Ongoing contact with NOAA/NCEP/EMC is maintained to communicate recommendations for ocean model improvement.

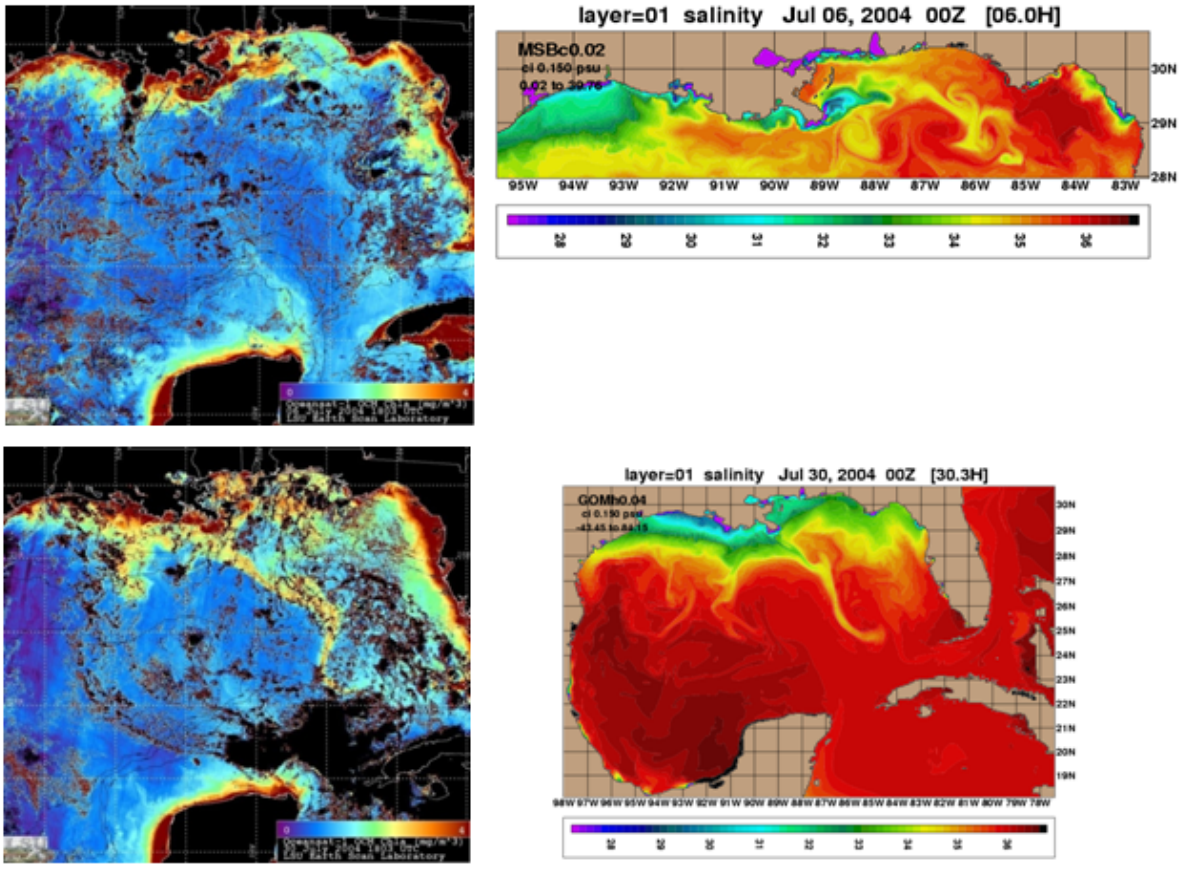


Two aspects of ocean model performance are illustrated here. The top two panels show the large differences in the upper ocean mixed layer thickness (solid black line) and thermal responses due to the impact of three-dimensional ocean dynamics, particularly wind-driven upwelling. The bottom four panels compare simulated and observed velocity components on the continental slope of the northern Gulf of Mexico. Velocity profiles and the associated current shear are critically important for the entrainment of colder water into the mixed layer.

Enabling and Initiating Observing System Simulation Experiments for the Gulf of Mexico

George Halliwell and Gustavo Goni

Project objectives are to quantify the contribution of new ocean observing systems to the quality of coastal nowcasts in the Gulf of Mexico region using Observing System Simulation Experiments (OSSEs). The strategy is to develop a nested system of (a) a high resolution coastal model in an area of strong coastal to offshore interactions and strong land-sea interactions (Northern Gulf of Mexico) and (b) a regional (Gulf of Mexico) model that will be used to perform the OSSEs. This study aims to elucidate and predict the transport and fate of river-borne waters on the Northern Gulf of Mexico and enable the performance of prototype Observing System Simulation Experiments and, thereby, guide the design of the Gulf Coastal Oceanographic Observing System (GCOOS). Additional information is provided in the Figure.

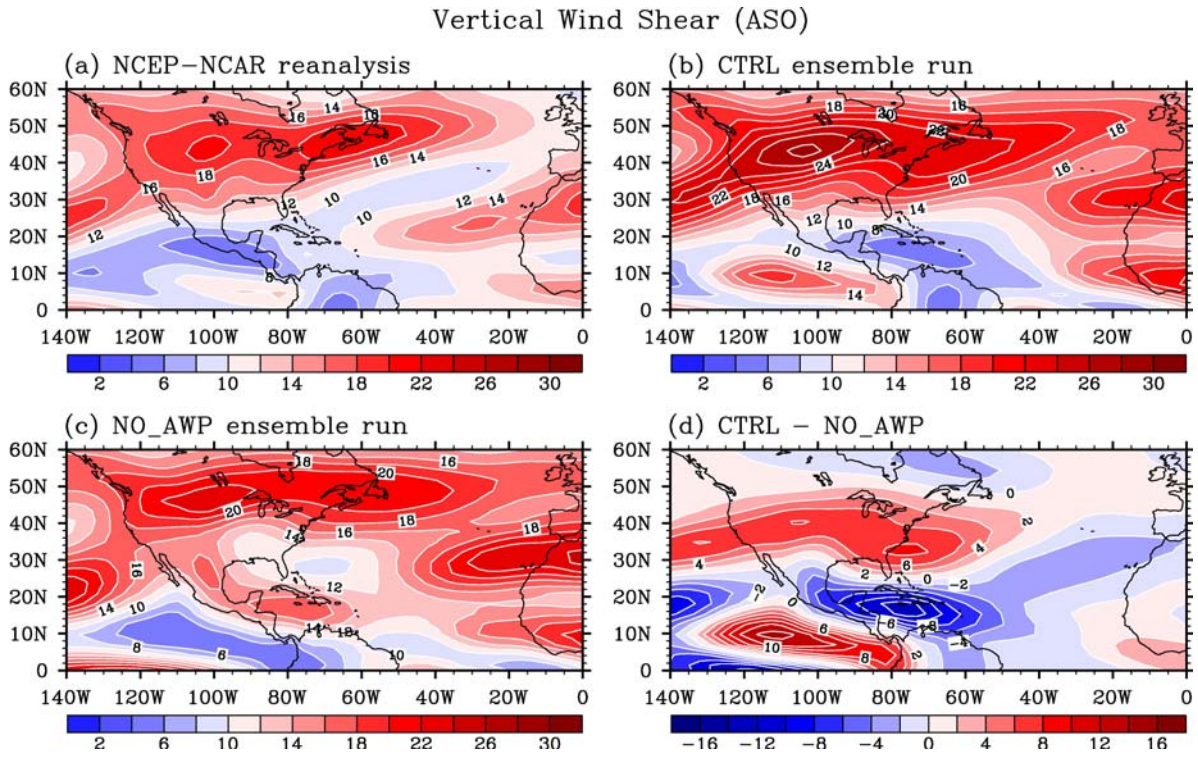


Comparison of satellite Ocean Color imagery provided by LSU and model derived Sea Surface Salinity from the high resolution Northern Gulf model (NGoM-HYCOM, upper right) and the regional Gulf of Mexico model (GoM-HYCOM, lower right, provided by NRL-SSC; data assimilation provided by NRL-MRY). The upper panels are for July 6, 2004, during a "young" Loop Current (away from the Northern Gulf); the lower panels are for July 30, 2004, during an "extended" Loop Current (approaching the Northern Gulf, near the Mississippi River delta). The eastward advection of Mississippi River waters (guided by the DeSoto canyon topography during light wind conditions) enhances the potential for offshore removal along the Loop Current front and toward the Straits of Florida.

Diagnostic and Modeling Studies on Impacts, Mechanisms and Predictability of the Atlantic Warm Pool

Chunzai Wang, David Enfield and Sang-Ki Lee

Our previous Climate Prediction Program for the Americas (CPPA) -funded research used the National Center for Atmospheric Research (NCAR) Community Atmospheric Model version 3 (CAM3) and observations shows the importance of the Atlantic Warm Pool (AWP) for North and Central American summer climate and hurricanes. In the current project, we will continue our investigation of the AWP by diagnosing coupled models and by performing coupled model runs using the NCAR Community Climate System Model version 3 (CCSM3) to assess and improve predictability of AWP and its climate impacts. Research topics include (1) variability of the AWP; (2) variability of the North Atlantic subtropical high; (3) variability of the easterly Caribbean low-level jet and its moisture transport; (4) variability of the southerly Great Plains low-level jet and its moisture transport; (5) the relationships of U.S. rainfall with the AWP, low-level jets and the North Atlantic subtropical high; (6) the effects of external influences versus local ocean-atmosphere processes on AWP variability; (7) the relationships among environmental factors contributing to Atlantic hurricanes; (8) extreme events such as tornados and Midwest floods and their relationships with moisture transport from the AWP region; and (9) models' biases in the AWP region and sources that contribute to the models' biases.

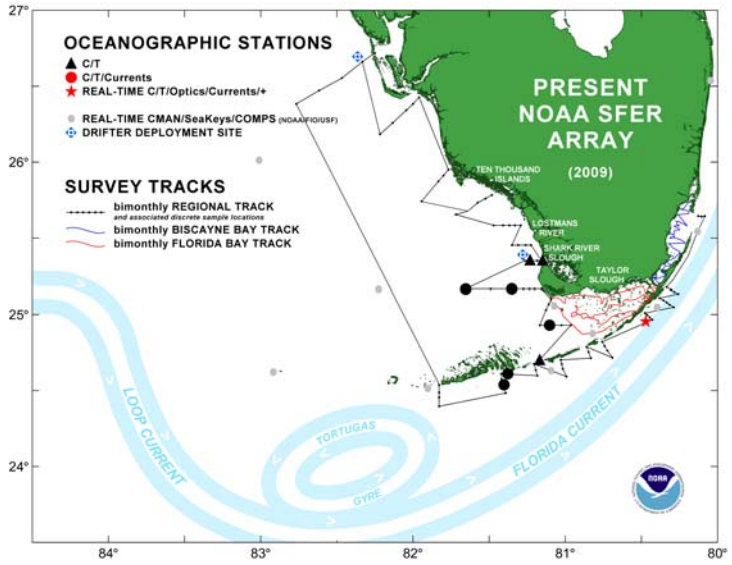


The tropospheric vertical wind shear (m s^{-1}) during August-September-October (ASO) from (a) the NCEP-NCAR reanalysis, (b) the CTRL ensemble run, (c) the NO_AWP ensemble run, and (d) the difference between the CTRL and NO_AWP runs.

South Florida Ecosystem Research Program

Elizabeth Johns, Chris Kelble and Ryan Smith

Since 1995, AOML has monitored south Florida coastal waters, studying the regional circulation, water quality, and salinity of the multiple nearshore marine habitats found in the area. This endeavor aims to assess the status of and develop predictive capabilities for the south Florida coastal marine ecosystem, gaining a more definitive understanding of the connectivity between nearshore areas and the Everglades. Understanding these linkages will help to ensure that Everglades restoration is beneficial to south Florida's economically and socially rich coastal habitats. To this end, the South Florida Ecosystem Research and Monitoring Program (SFER) supports the Comprehensive Everglades Restoration Plan (CERP), providing coordinated measurements of coastal physics, biology, and chemistry for analytical interpretation of the coupled local, regional, and remote processes influencing the transport and exchange of South Florida coastal waters and their suspended or dissolved constituents. Data from the southwest Florida shelf, Florida and Biscayne Bays, and the Florida Keys reef tract are collected via regular shipboard surveys and the program's moored array. Originally funded by NOAA, SFER is currently funded by the Army Corps of Engineers (USACE).



SFER regional monitoring efforts including ship survey tracks, mooring sites, and drifter deployment locations.

SFER supports NOAA's Ecosystem Research Program (ERP) within the ecosystem goal to "Protect, Restore, and Manage the Use of Coastal and Ocean Resources through an Ecosystem Approach to Management." Outputs from this project are utilized to develop Integrated Ecosystem Assessment (IEA) capabilities within ERP. This project directly aligns with the first statement in the requirement drivers for ERP: "The ERP is governed by a series of statutes that require NOAA to provide managers with scientific knowledge, increased management capabilities, financial assistance, and other support to manage the coastal zone to support society's needs". SFER is by design supporting restoration managers and enabling the implementation of adaptive management to better manage south Florida's coastal ecosystem and optimally restore the entire south Florida ecosystem, both terrestrial and marine.

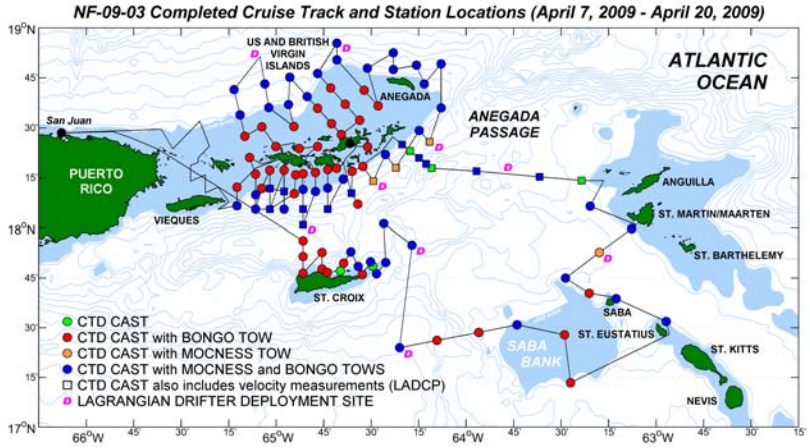
The USVI Larval Reef Fish Recruitment, Distribution, and Supply Study

Ryan Smith and Elizabeth Johns

The United States Virgin Islands' (USVI) Grammanik Bank is the site of a multi-species spawning aggregation for economically important reef fish including yellowfin grouper, Nassau grouper, tiger grouper, and dog snapper. Fishing pressure at this suspected source of larval recruits prompted the US Caribbean Fishery Management Council (CFMC) in 2005 to close the bank yearly from February to April. Additional unprotected banks south of the USVI and the British Virgin Islands (BVI) also provide similar habitats and spawning aggregation sites. Prior to the inception of this study, the biological and physical processes which drive production on these banks, and the circulation connecting these areas, had not been quantified. As a result, regional Marine Protected Area (MPA) designations and temporary closures are presently based on professional judgment rather than quantifiable, defensible scientific information.

In 2007, AOML and Southeast Fisheries Science Center (SEFSC) scientists, working in conjunction with the University of the Virgin Islands (UVI) and the USVI Department of Planning and Natural Resources (DPNR), began an ongoing research project conducting biological and physical oceanographic surveys of the Virgin Islands (VI) bank ecosystems and surrounding regional waters. The long-term sustainability of regional fisheries will depend on a comprehensive understanding of regional spawning aggregations, larval transport, and overall larval recruitment in the study area. To date, this project, funded by NOAA's Coral Reef Conservation Program (CRCP), has produced a unique dataset, pairing biological and oceanographic data in an effort to gain a better understanding of marine ecosystem connectivity and larval recruitment pathways in the USVI and surrounding region.

Additionally, though this research is primarily ecosystems oriented, data collected may also answer climate related questions. Project cruises regularly maintain a multi-year mass transport time-series at Anegada Passage. One of only two deep inflow pathways to the Caribbean, transport variability at Anegada has implications for large-scale circulation in the North Atlantic and climate change. Deep inflow through this passage helps to ventilate the abyssal Caribbean, while upper layer water masses ultimately contribute to the Gulf Stream system in the North Atlantic. Improving our understanding of Atlantic inflow through the Caribbean passages is critical to understanding the variability of the Meridional Overturning Circulation (MOC) in the Atlantic Ocean. Multi-year biological, chemical, and water mass time-series data collected as part of this ongoing program may also yield a better understanding of climate change impacts on economically important US Caribbean fisheries.

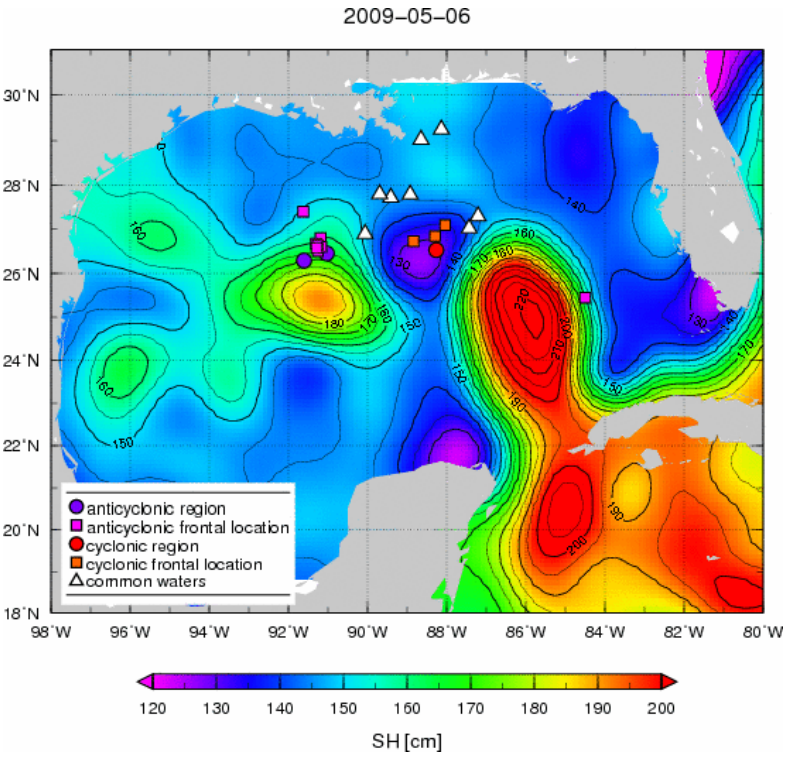


Stations completed during the 2009 USVI Larval Reef Fish Recruitment, Distribution, and Supply Study annual survey of the northeastern Caribbean Sea conducted aboard the NOAA Ship Nancy Foster are shown above.

The use of satellite derived oceanographic data for fish stock assessment in the Gulf of Mexico

Gustavo Goni and Francis Bringas

Ocean parameters and data of fish catches are being used to investigate the link between ocean dynamics and stock assessment of several species in the Gulf of Mexico. The oceanographic data includes sea surface temperature (SST), sea height anomaly (SHA), chlorophyll A and derived products, such as eddy kinetic energy (EKE) and sea surface height (SH). The data of catches correspond to bluefin tuna (BFT), yellowfin tuna (YFT) and swordfish (SWO) and were obtained from a U.S. longline fleet operating in the Gulf of Mexico. A methodology based on the oceanographic observations was developed to determine whether captures occurred in regions of anticyclonic or cyclonic features, frontal locations or in Gulf common waters. Results show that Catches of BFT, YFT and SWO were not homogeneous in space and time as reflected by their Catch-Per-Unit-of-Effort (CPUE). BFT catches seem to be associated with temperatures below 27.2°C, while YFT catches were associated to higher temperatures. BFT CPUE showed a 'dome shape' response to SHA, SH, SH gradient, ocean color, and EKE with highest values associated to the frontal areas of the cyclonic rings. BFT CPUE was zero in areas associated to anticyclonic rings. Lower fishing effort in areas dominated by anticyclonic features diminished the capability of drawing sound conclusions on the relationship between CPUE and these features. The qualitatively different responses of the CPUE of BFT, YFT and SWO to oceanographic features could be used to locate specific areas were the catches of a certain target species could be enhanced while reducing the incidental catch of non-target species. At the present time, estimation procedures used to standardize catch rates (CPUE) for the US pelagic longline fleet do not include environmental observations. Identifying the oceanographic features that affect catch rates is the first step towards the incorporation of environment effects in the process of stock assessment and ecosystem based management.



Captures of bluefin tuna, yellowfin tuna and swordfish are linked with the oceanographic features in the region. Each location is labeled according to the ocean dynamics: anticyclonic feature, cyclonic feature, frontal region, or common waters, based on values of sea height and on the horizontal gradient of sea height. The most important features of the region are revealed by the field of sea height, where cyclonic and anticyclonic rings and the main location of the Loop Current can be observed.

Routine Shipboard Surveys of Regional and Worldwide Field Operations During October 2008 – September 2009

Blue Water Cruises

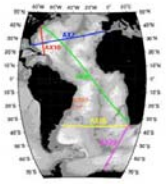
Cruise	# of cruises	Days
Indian O. Hyd	1	45
PNE	1	31
CLIVAR CO2	2	70
WBTS-FC	3	7
WBTS-BBM	10	10
WBTS-ABACO	1	27
Nancy Foster	1	14

19 cruises, 204 days

Personnel (13): U. Rivero, **P. Pena**, M. Adler, E. Valdes, R. Smith, K. Seaton, **G. Rawson**, C. Meinen, A. Stefanick, C. Fonseca, E. Munoz, N. Melo, C. Schmid, R. Lumpkin.

High Density XBT Transect Cruises

Transe	number	days
AX07	4	35
AX08	5	80
AX10	4	16
AX18	3	27
AX25	2	22
AX97	4	9



22 cruises, 189 days

Personnel (6-6): G. Rawson, S. Pochan, J. Farrington, P. DiNezio, **P. Pena**, F. Bringas, A. Webb, Z. Gebhardt, F. Mckay, A. Troisi, W. Reynoso, M. Caspel.

South Florida Cruises

Cruise	number	days
Biscayne Bay/V.K.	5	12
RT moorings	10	10
Looe Key	3	3
No RT	3	3
S.Fla/ W.S.	4	24
Q. Interdisc. Survey	3	19

28 cruises, 71 days

Personnel (9): N. Melo, **G. Rawson**, S. Dolk, E. Valdes, **P. Pena**, C. Fonseca, K. Seaton, L. Johns, R. Smith.

Shipboard Surveys of Regional and Worldwide Field Operations

South Florida Ecosystem Research (SFER). Goals – To quantify the regional circulation, water quality, and salinity of south Florida coastal waters, covering the southwest Florida Shelf, Florida and Biscayne Bays, and the Florida Keys reef tract. This long-term research endeavor is conducted in support of the Comprehensive Everglades Restoration Program (CERP). The project is a collaboration between AOML/PhOD and AOML/OCD and has included partners from UM/RSMAS in years past. The size of the SFER moored array and the interval of regular shipboard surveys have evolved over the course of the program. Presently, SFER operational components include:

1. SFER moored array: 9 moorings distributed throughout the south Florida coastal ocean.
2. Bimonthly 3-day surveys of Biscayne Bay and Florida Bay via the program's shallow draft research catamaran the *R/V Virginia K* (2-3 PhOD personnel per cruise).
3. Bimonthly 5-7 day regional surveys of south Florida coastal waters via the UM's *R/V F. G. Walton Smith* (4-6 PHOD/OCD personnel per cruise).

U.S. Virgin Islands Larval Reef Fish Distribution and Supply Study: Goals – (1) To determine the regional larval transport and recruitment pathways of economically important reef fish of the US Virgin Islands (USVI) including species of snapper and grouper. (2) To gain a more comprehensive understanding of the regional connectivity between USVI marine ecosystems and the surrounding region. Understanding these dynamics and life history patterns will help determine the effectiveness of Marine Protected Areas established at regional spawning aggregation sites. Additionally, results will aid managers in developing new strategies for future sites. This research project is a collaborative endeavor between AOML/PhOD and SEFSC/ Early Life History Laboratory, which began in 2007. Operational components of the USVI Larval Reef Fish Distribution and supply study include:

Annual ~14-day research surveys of the northeastern Caribbean, conducted aboard the *NOAA Ship Nancy Foster* (4 PHOD personnel per cruise). Biological net tows are conducted simultaneously with oceanographic measurements to tie the larval catch with the underlying physical processes.

CLIVAR CO2/Repeat Hydrography: Goals – To monitor changes in water properties on a decadal time scales. The program is a collaboration between NOAA and NSF with many partners nationally and internationally. Within NOAA, the program is collaboration between AOML/OCD, AOML/PHOD and Pacific Marine Environmental Laboratory (PMEL). PHODs responsibility includes support for CTD observations and discrete salinity and oxygen measurements.

Typically two major cruise every three years are conducted on a subset of the global hosorical survey lines. PHOD is responsible for sending two discrete oxygen analysts, one salinity analyst and a CTD engineer. Cruises are generally quite long ranging from 30 to 60 days.

PIRATA Northeast Extension (PNE): Goals – To study both ocean and atmosphere in the tropical eastern Atlantic. The program routinely has partner/piggy-back programs from Earth System Research Laboratory (ESRL), University of Miami, and Howard University. Number of PHOD people going on each cruise: 3-5 and typically involves a CTD survey along 20ºW and the annual servicing of three PIRATA moorings located along 20ºN and 20ºW. The operational components include:

1. Normally one cruise per year ranging from 30 to 35 days depending on the ports of call.
2. In 2010 the PNE cruise will move from a spring/summer (May-June-July) time window to a fall (October-November-December) time window, and as a result during 2010 there will be two PNE cruises, one in February and one in October/November.

Western Boundary Time Series (WBTS): Goals – To study the components of the meridional overturning circulation near the western boundary of the Atlantic basin at 26.5^{o}N. Presently, the WBTS program includes the following sea-going two major components:

Florida Current measurements along 27^{o}N: These cruises have several goals that include determining the volume and heat transport in the Florida Straits to use for calibration of the submarine cable voltage measurements, to provide boundary current transports for the determination of the meridional heat and volume transport associated with the XBT line AX7 and the MOCHA/Rapid program (see below). These measurements include:

1. Small charter boat one day cruises: These cruises are done on a chartered fishing boat from the Sailfish Marina in West Palm Beach and involve sending one person with an AOML designed dropsonde/CTD that provide profiles of temperature and salinity and the vertically averaged horizontal velocity. Eight to ten cruises each year are timed to occur within a two week period quarterly coinciding with the high density XBT transect AX7.

2. Coastal Survey Vessel 2 to 3 day cruises typically using the R/V Walton Smith: These cruises are planned for quarterly occupation (subject to ship time charter funding) and involve three people. Data resulting from these cruises include profiles of temperature salinity, oxygen and velocity (from lowered and shipboard ADCP measurements). Starting in 2009, these cruises include net tows in collaboration with the NOAA Southeast Fishery Science Center. Starting in 2008 these cruises include annual servicing of moored instruments to measure sea level differences across the Florida Straits and acoustic travel time (using moored inverted echosounders).

Deep Western Boundary Current cruises along 26.5^{o}N: These cruises seek to quantify water mass variability in the Deep Western Boundary Current east of the Bahamas and to provide an estimate of the volume flow. Since 2004 insitu PIES & CPIES moorings provide time series estimates of the DWBC (and the smaller northward flowing Antilles Current) and cruises include servicing (as appropriate) and downloading the subsurface

data (via telemetry). In addition to travel time series data, these cruise provide full water column estimates of temperature, salinity, oxygen, and velocity east of the Bahamas, along 26°N, 27°N in the Florida Straits, and near 78°W across the Northwest Providence Channel (time permitting).

Meridional Overturning Circulation Heat-flux Array (MOCHA): Goals: To determine the basin-wide meridional overturning circulation at 26.5°N. This is a collaborative program between NOAA, NSF and the United Kingdom Natural Environment Research Council (NERC) and builds on the longstanding NOAA Western Boundary Time Series Program (see above). The NSF funded part of the program is called MOCHA, while the UK funded part is called RAPID-MOC.

Expendable Bathythermograph (XBT) transects: Goals: To measure the upper ocean mesoscale temperature variability in the Atlantic Ocean using expendable bathythermographs deployed with horizontal separation of 10-50 km. Six high density XBT lines are maintained by AOML with sampling typically quarterly for a total of 24 sections each year. With the notable exceptions that AX25 is repeated twice each year and AX97 is repeated six times per year. Each transect requires one ship rider to deploy XBTs, drifters and Argo floats. Brazilian, Argentineans and South African collaborators/contractors staff a vast majority of these sections, with AOML personnel covering the two North Atlantic transects AX07 and AX10. The length of these cruises ranges from up to 35 days (AX25 and AX08) to a few days (AX10 and AX97).

Some of our National and International Partners

Recent PhOD Publications
(PhOD personnel in bold)

2010

Biastoch, A., L. Beal, J.R.E. Lutjeharms, and **T. G. D. CASAL,** (2010). "Variability and coherence of the Agulhas Undercurrent in a high-resolution Ocean General Circulation Model". *Journal of Physical Oceanography*, 39 (10), 2417-2435.

Cunningham, S., **M. BARINGER**, J. Toole, S. Osterhaus, J. Fischer, A. Piola, E. McDonagah, S. Lozier, U. Send, T. Kanzow, J. Marotzke, M. Rhein, **S. GARZOLI**, S. Rintoul, S. Speich, S. Wijffels, S. Talley, J. Baehr, **C. MEINEN**, A-M. Treguier and P. Lhernminier, (2010). "The present and future system for measuring the Atlantic meridional overturning circulation and heat transport" in Proceedings of the "OceanObs'09: Sustained Ocean Observations and Information for Society" Conference (Vol. 2), Venice, Italy, 21-25 September 2009, Hall, J., Harrison D.E. and Stammer, D., Eds., ESA Publication WPP-306.

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